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Automation Industries, Inc., Silver Spring, Md.

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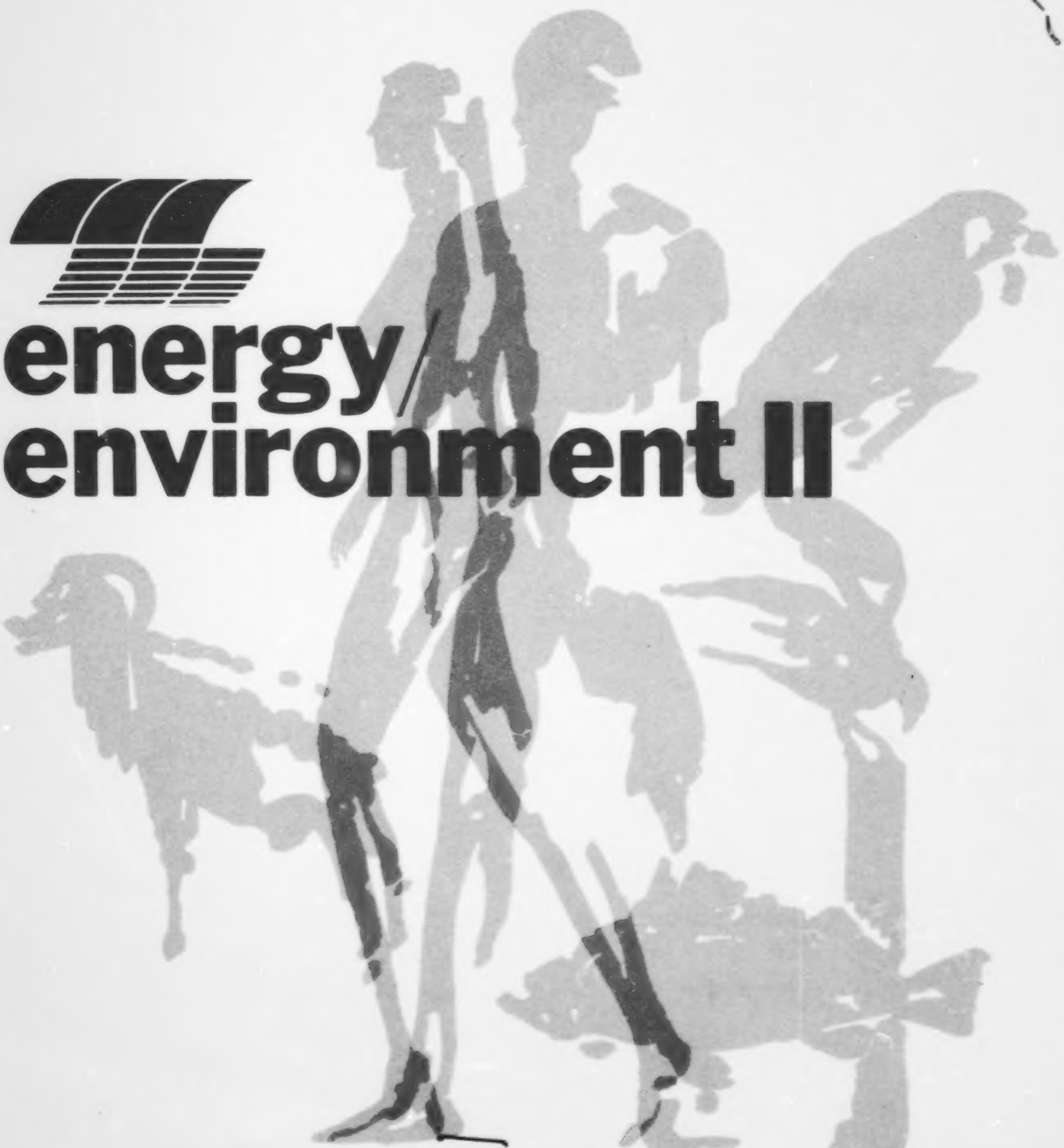

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the energy/environment R&D decision series

This volume is part of the Energy/Environment R&D Decision Series. The series presents the key issues and findings of the Federal Interagency Energy/Environment Research and Development Program in a format conducive to efficient information transfer. The Interagency Program was inaugurated in fiscal year 1975. Planned and coordinated by the Environmental Protection Agency (EPA), research projects supported by the program range from the analysis of health and environmental effects of energy systems to the development of environmental control technologies. The works in this series reflect the full range of program concerns.

The Decision Series is produced for both energy/environment decision-makers and the interested public. If you have any comments or questions, please write to Series Editor Richard Laska, Office of Energy, Minerals and Industry, RD-681, U.S. EPA, Washington, D.C. 20460 or call (202) 755-4857. This document is available either from the Series Editor or through the National Technical Information Service, Springfield, Virginia 22161. Mention of trade names or commercial products herein does not constitute EPA endorsement or recommendation for use.

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FOREWORD

The Interagency Program links more than a dozen Federal agencies whose shared goal is to assure that our energy development efforts are supported by an effective environmental R&D program. In pursuit of this goal, the coordinator of the Interagency Program, the Office of Energy, Minerals and Industry within EPA's ORD, has invested $430 million since fiscal year 1975. For this $430 million, significant accomplishments have been achieved, and significant progress made. To review this progress, the Second National Conference on the Interagency Energy/Environment R&D Program was held in Washington, D.C. on June 6 and 7, 1977. This report is based upon that conference.

Energy/Environment II provides a current update of Interagency research and shows the direction we are taking to help solve the energy/environment dilemma. Included are the addresses and papers delivered at the conference, as well as the discussion periods which followed each session.

Our gratitude goes out to all those who, through their effort and participation, made the conference such a success. The greatest challenge we face today is twofold: we must have enough energy to maintain our way of life, and we must ensure that our energy is used in environmentally sound ways. With the combined efforts of all involved, the Interagency Program is working to ensure that these two goals are compatible, and that they are being achieved.

Steven Reznek

Steven R. Reznek
Acting Deputy Assistant Administrator
Energy, Minerals and Industry

NOTE: This text was prepared using the titles and descriptions of individuals participating as of the date of the conference and consequently does not reflect recent changes due to the creation of the Department of Energy.

ABSTRACT

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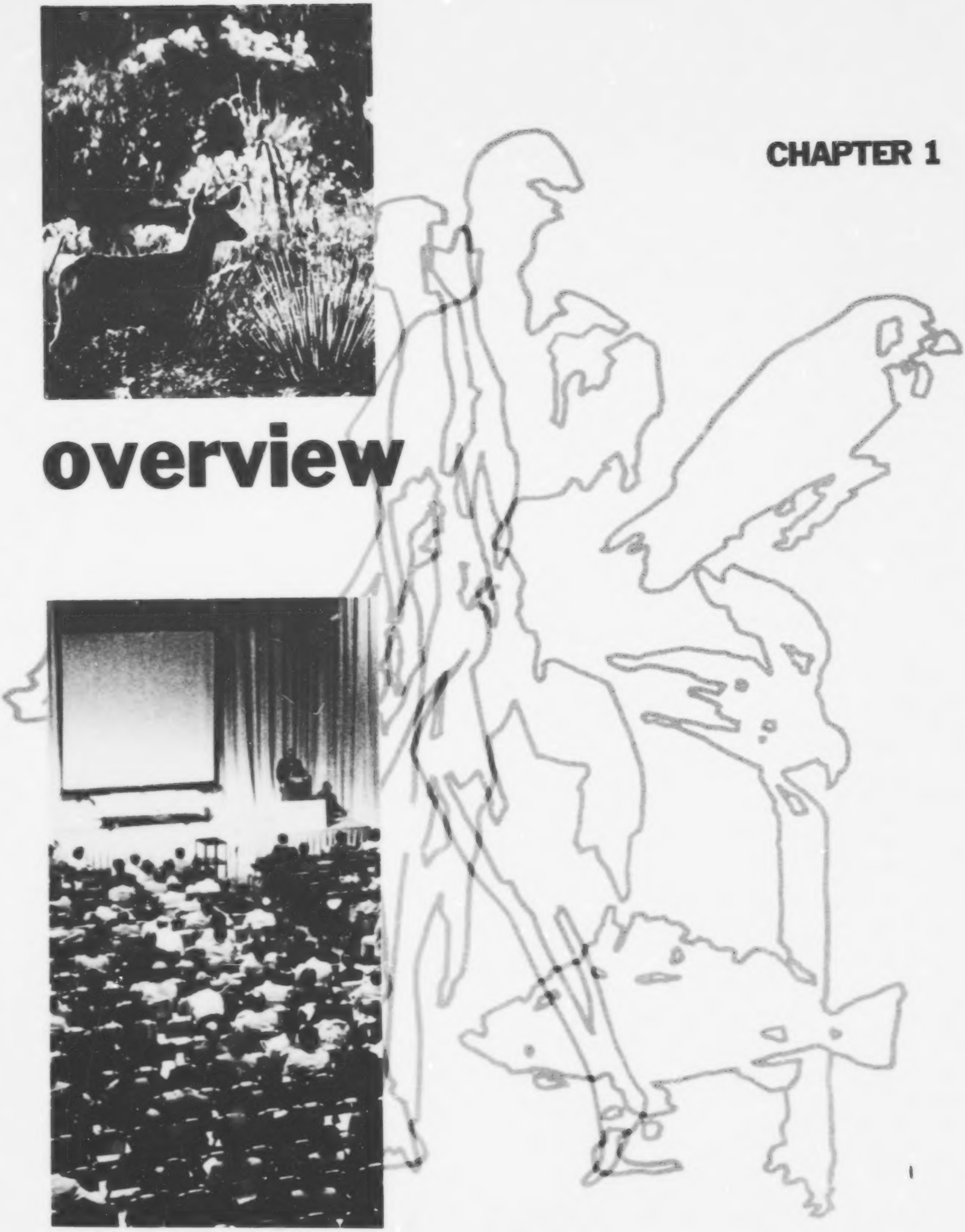
CHAPTER 1

overview



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OVERVIEW

introductory remarks

The Honorable John F. O'Leary
Deputy Secretary
Department of Energy

part I

EITHER OR SITUATION

Up until now there was the general conviction that we had to be in a position to exploit our mineral resources at some unavoidable cost to the environment or we had to be in a position to protect the environment at some unavoidable cost to mineral and energy resource exploitation.

That may be true in the short run because we have been foolish in our attitude with regard to basic energy resources; but I am convinced, and really this is the operating assumption that I have brought to the FEA, that in the intermediate term and certainly in the long term, we do not have to make that choice. We can indeed have the careful attention to environmental concerns that I think is essential for the future of this country, and we can have adequate energy to fuel the things that we want to do. I do not think that we have to regard this as an either/or situation. If I really believed that essentially we had to make a choice between energy on the one hand and the environment on the other, I would opt for the environment, largely because the crucial element in this entire equation of human living is not so much the material things of life but rather the aesthetic, the spiritual. If we trample on those in the enormous onrushing charge for material progress, I think that we may benefit for a short period of time, but certainly the counter-pressures on society that will flow from a badly abused environment will make that choice not worth a candle.

LACK OF FORESIGHT

Now, let me tell you fundamentally how I look at this conflict. We are in an energy crisis largely because we have been stupid in the handling of our resource-related activities. The inherent problem is that we did not take advantage of signals that were available to us a long time back and we did not begin to work for an orderly transition from the day of fossil fuel dependence, particularly oil and gas dependence, to its successor technologies.

Today after only 3 years of serious attention to solar energy, for example, we have brought the prospective price of solar electric energy down by almost two orders of magnitude. We have had a very short-lived research activity and few people have been involved in it. Think of where we will be in another 5 or 6 years with regard to solar electric energy. Where would we be today if we had begun that effort in 1950 rather than in 1972 or 1973. It is clear that we would have had an orderly transit from the hard fuels to soft energy resources during the 1970 to 1980 time-frame without the severe disruption that has come to us.

WORK UNDER SYNTHETIC LIQUID FUELS ACT TERMINATED

Let me give you another example. I was involved early in the exploratory work on new frontier technologies for the conversion of oil and gas. I can well recall the perturbation of those of us who were in or close to the Bureau of Mines when in 1954 all of the work that was then being conducted by the Department of the Interior under the Synthetic Liquid Fuels Act of 1947 was abruptly terminated.

In 1947 we began two serious R&D efforts aimed at future energy technology. One, of course, was the light water reactor work that later brought us to the full commercial exploitation and deployment of the current generation of both boiling water and pressurized water reactors. The other R&D effort, which began about the same time, was to determine what to do with fossil fuels to turn our oil shale and coal into more useful forms. As I have said, that work was begun in 1947 under the Synthetic Liquid Fuels Act by the Department of Interior, principally by the Bureau of Mines. Most of the work that we will be drawing on in the years to come for coal and shale conversion was conducted under that program. Between 1947 and 1957 the Bureau spent almost $100 million. It developed the onground retort at Rifle; did the work at Louisiana-Missouri, bringing German technology for coal synthesis to the United States and somewhat updating it; and it did work in *in situ* gasification of coal.

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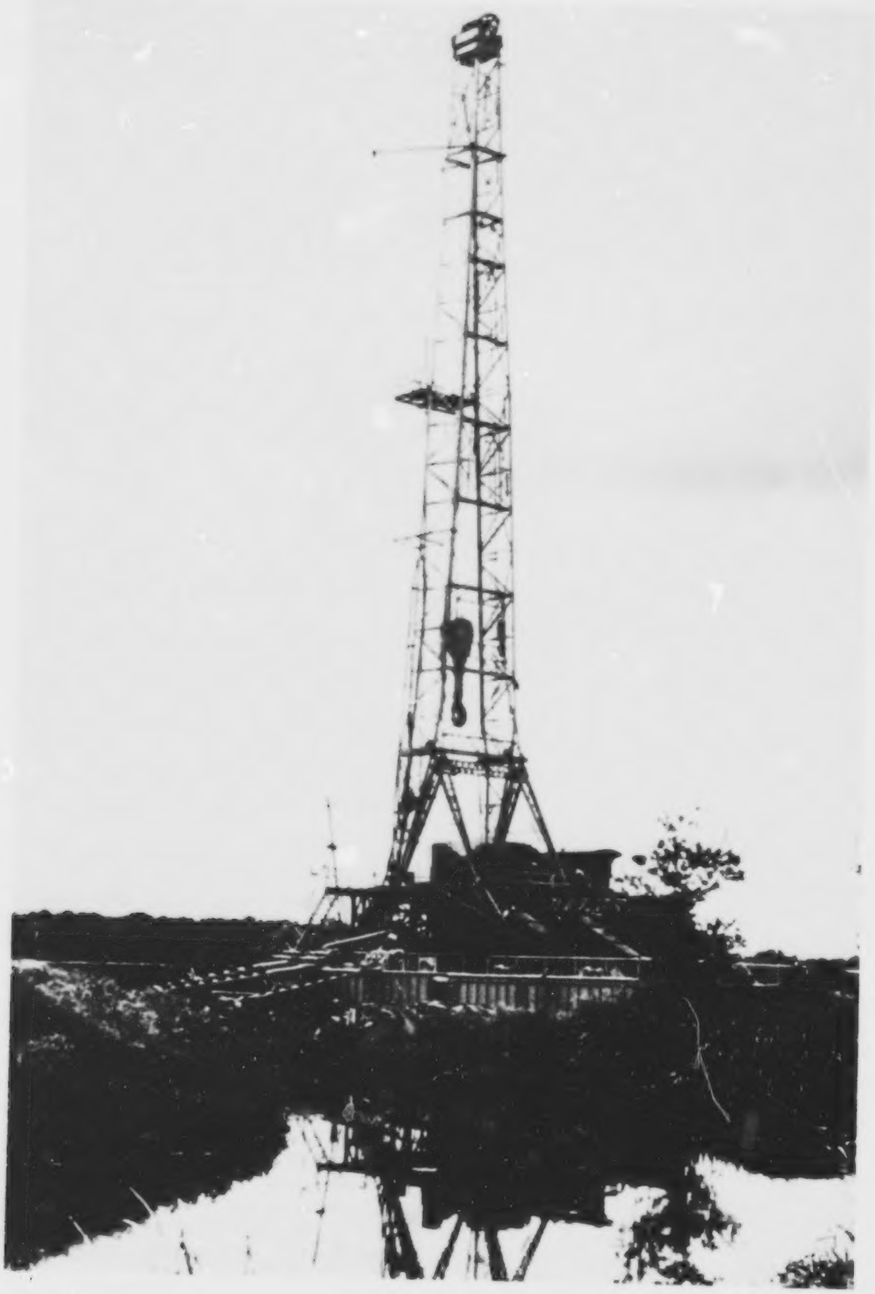
To repeat, suddenly in 1954 with the advent of the Eisenhower administration, that work was abruptly chopped off. The reason for it was straightforward. The oil industry did not like the work that was being done by the Department of Interior because it took the view, and only recently has the oil industry softened on this view, that the government should not indulge in research that influenced inter-fuel competition. And they very rightly recognized that if the government launched a substantial program towards coal synthesis, solar or wind power, or geothermal, that to the degree that the government could improve the economics thereby, they would in fact influence inter-fuel competition. The oil industry thought that was an improper function for government. During the discussions of the fifties and sixties, the oil industry said the appropriate R&D role for government should be confined to basic research, by which they meant understanding the basic nature, for example, of the hydrocarbon molecule and not do anything at all in the applied side of the equation that bears upon the marketplace.



NEED FOR SYNTHETIC GAS & OIL

During that time, we who were close to the business warned that it would not be very long before we were going to need synthetic gas and maybe synthetic oil, but the oil industry contended that when that time came we would do it. I want you to remember that as we have these debates on R&D policy over the next few years. In fact, when that time came, it was not done. The government had been taken out of the track. The industry had not done it for a variety of reasons. When we got to the point where we needed advanced technology for coal synthesis, we had essentially two choices. We could go back to 1926 lurgi technology—1926 in the sense that that was the year in which it was intially piloted for coal gasification—or to Fisher-Troche synthesis technology for the production of liquids that again had been piloted in Germany during the 1930's. We do not have a successor technology in this country in either case, and certainly in the case of gas, we will not have a successor technology for another 10 years.

Does that mean that it cannot be done? No, not at all. It means that we have been stupid and have gotten ourselves to the point where the lead times have so contracted on us that we do not have the time to get it done.

If in fact you were to go back and take a look at the energy history of this country over the last 10 years, you would find that it has been characterized by narrowing options. For example, put yourself in the position of a 1965 or 1967 utility executive who is about to build a new 1,000 megawatt plant for the generation of electricity. Depending on the part of the country in which he found himself, he could say, shall I use gas? There is an assured supply. I am told by the government and by industry that we will have gas for another 100 years. It will be cheap. It is certainly environmentally benevolent, although in 1967 that was not a concern of the utility industry, but to the degree that he thought about that at all, he would say yes, that is a good one. Or he would say how about oil? And he would say that right now we have almost 3 million barrels a day of shut-in capacity for oil in this country. The price is low. Supplies are pressing on the market from abroad. We have an oil import control program as evidence that supplies are pressing on the market. And it seems to me that that is a good, solid choice for my generating plant. Or he would consider a coal-fired plant. Here again, there are no particular problems. You can mine the coal, you can burn it. The transportation system is intact, and certainly there are no problems there. Then he would consider nuclear energy? Here is a new source coming down the way, not fully proven yet but certainly a lot of my colleagues in the utility industry have bought these plants. It takes only 5 or 6 years to run them through the cycle and get them up and running. Maybe I will build a nuclear plant.

1977 NARROWING ENERGY OPTIONS

Now, contrast the above example to the situation today. If the 1977 executive looks at gas, he realizes that the supply is not there. We have not had new gas orders for the last 2 years. If it were to be available in the interstate market, it would only be availble for a short period of time and at a very high cost, a cost that cleared with oil in all likelihood. The oil supply position is very iffy. He has found that the enormous surplus of 1967 has disappeared entirely. Those supplies pressing on the market that necessitated an oil import control program, which I will remind you ran until just 4 years ago, have disappeared and the price has gone up in world markets by a factor of five over that short period of time. If he looks at the coal-fire plant, he finds that there is an enormous confusion. Is he going to be building a white elephant? Will he, with the insulation of the technology available to him today, be able to run that plant without interruptions 5 years from now? What are the air quality constraints that will be operative there? And furthermore, can the coal be mined and transported in the necessary time frame for the operation of the plant? As for considering a nuclear plant, the 6-year promise of 1967 is now a 13-year promise and the price has gone from $200 per installed kilowatt to $1,100 per installed kilowatt. All in all, the position of that utility executive, as simply a surrogate in these remarks for anyone who is making energy choices, has gotten to the point where we have seen a great convergence of options over this relatively short period of time.

EXPANSION OF ENERGY OPTIONS

We have to recognize that the principal function of government in this R&D area is to expand those options, and it is important that that expansion be undertaken with an absolute ironclad assurance that it will not be done at the expense of the environment. The fundamental reason for that is fairly straightforward. I have used the words foolish and stupid to characterize how we got into our situation on energy. We got into the situation not because of resource constraints but because of constraints on particular kinds of resources. If we look at the ways of making adequate supplies of energy from solar on down to geothermal to wind power to exotic forms of production of hydrogen fuels and from them hydrogen and carbon combinations into methane type equivalents, there simply is no conceivable resource constraint as far out ahead as we can see. The world from the standpoint of our resource position is simply unlimited in its offering of energy choices.

UNLIMITED ENVIRONMENTAL INSULT

The capacity of the world to accept environmental insult, however, is not unlimited. Consequently, when we make these choices, we are going to have to spend that extra 10 to 12 percent, for example, in order to get best available control technology so that we can burn coal and at the same time not add to the environmental insult. In conjunction with that, as we increase coal burning, we are going to have to back off the environmental degradation from other burning sources, so as not to aggravate the air quality. We are going to have to find ways in which we can handle this without further degradation of water quality in this country. There is, for example, now enormous concentration on the impact of the drought in the western part of the United States and a growing realization that we are beginning to get to the limits of our capability to continue growth where water is regarded as a zero cost kind of commodity. All of the principal interests in water are governed by tradition and not by any economic or environmental concerns. Out of that lesson over the next 4 or 5 years we will begin to move in the direction of finding very fundamental ways in which we can begin to do even better environmentally than has been the case in the recent past. We can bring a better understanding of a problem and, if you will pardon this from an economist, an understanding of the economics that are involved in a more efficient regime of water use in the water-short areas of the west.

LAND USE

With regard to land use, the hidden war between the environmentalists and the developers over the last 10 years has been staged on the question of what are we going to do with the land. We are finding this in the Congressional discussion of the strip mining bill that is now, happily, coming to an end of a 4-year fight through the Congress and hopefully within the next couple of months will go to the President to be signed. In that discussion we did not just talk about mining. We talked about water use, agricultural use, aesthetics, and, in a small way, the great debate over strip mine restoration really ran to the question of land use in this country. I think that you have found that FEA has been very sympathetic to the objectives of those who reasonably wanted to constrain mining when it threatened the good, sound use of the land.

Some of the things that I am sure you will be concentrating on as you go along are how does research run into this? What sort of a world do we want in the future? What is the tradeoff between energy on the one hand and the environmental concerns on the other? The thing that I want to restate that should be the guiding light for you and certainly has been for me at least in looking at the energy situation is that from the standpoint of the long term—that is to say, when we finally recognize this problem and begin to deal with it—we can have any sort of an energy economy we want. If, however, we do not begin today to spend a renewed effort on the environmental side of this equation, we will not care about the energy economy because there will not be anything here much to preserve.

JOHN F. O'LEARY

B.A., Economics, George Washington University. Twenty-two years energy related service including commodity specialist, economist, and energy consultant. Served as Deputy Assistant Secretary of Interior for Mineral Resources, Chief of Bureau of Natural Gas at Federal Power Commission, and Director of Bureau of Mines. Was Technical Director of Energy and Environmental Programs for a large private firm. Was then appointed Director of Licensing for Atomic Energy Commission responsible for licensing nuclear power plants and conducting comprehensive safety, environmental, and antitrust reviews of these plants. While Director of New Mexico's Energy Resources, helped establish state energy policy and plans for energy development. Served as Administrator of the Federal Energy Administration. Currently, Deputy Secretary, Department of Energy, Washington, DC.

questions & answers

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Vanderbilt University

Mr. George Scudella
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Florida Power and Light

Mr. Francis R. Hull
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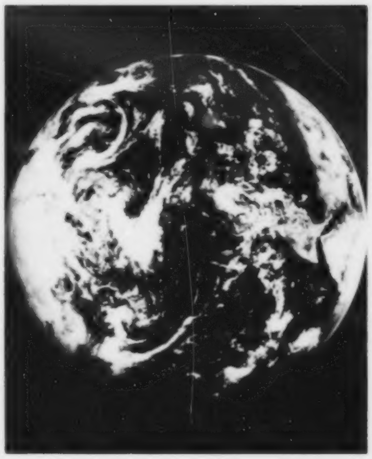


QUESTION: The Wall Street Journal said that there is a thousand years of natural gas available, and it is only the federal policies that are preventing it from coming to the market. Would you like to comment on that?

RESPONSE: Mr. John F. O'Leary (FEA)

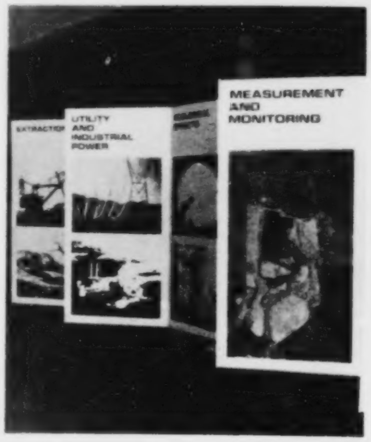
I personally disagree with that statement. It is, however, something that we should be very careful about. There are two schools of thought about today's energy crisis. Credible and respectable people; not parties to self-interest themselves, for example, the U.S. Geological Survey, take the view that, indeed, we do have a serious gas resource problem.

The other school takes the view that we are the victims of a conspiracy, that the oil and gas interests in the country have determined that they are going to sit on their reserves, that they simply do not like regulation, and that over the last few years they have systematically understated reserves, quite deliberately avoided additional drilling, and created from a bountiful resource position an apparent shortage. And there are, of course, many views between these schools of thought.

I belong to the first school. I think that we have a genuine resource problem. On the basis of all of the measures that I can assimilate, this view is borne out.

First, as a result of the price increases, particularly the price increases in Texas in the last 5 years, we find that there has been a substantial increase in all of the conventional indicators of petroleum drilling activity. (Beginning in about 1971, Texas departed from the interstate market and began to go into a more or less free market. So that gives us a fairly good run of history.) The rig rate use in Texas is double what it was 6 years ago. The number of feet drilled has doubled. The number of wells completed has doubled, and production of both gas and oil is off; production of gas is off about

20 percent and continues to decline each year. Those nationwide indicators suggest that the thesis presented by the Wall Street Journal article is not correct. As I recall, the Journal said that, at about $1, there are ample supplies to meet all of our requirements for as long as we are going to be interested in natural gas. That may be when we begin to move from today's conventional gas resources into the geopressurized resources that are around the Gulf of Mexico. These involve the production of about 5 tons of water that is heavily mineralized and heavily corrosive for the production of every MCF of gas. If it were done in large volumes and simply dumped into the sea, it would in time significantly influence salinity and other mineral content of the Gulf and have undesirable changes in the ecology. Consequently, it is ruled out on that account. However, if we can find ways to avoid violence to the environment while producing those resources, I think that we have another 50 years or maybe even longer to go.



Let me give you some fundamental arithmetic that we ought to bear in mind as we hear the conspiracy theory. We hear, for example, that we have from 500 to 3,000 years of coal reserves, and then we hear in a small whisper (at present rates of use). Taken from the American Gas Association numbers, we had at the beginning of the oil and gas activity in this country about 1,700 trillion cubic feet of gas as a resource, not as a reserve. That is the ultimate finding. By 1930 we were using 1 trillion cubic feet. If that first number was right, by the same sort of logic we had thousands of years of coal supplies, in fact, a 1700-year supply of gas.

We began to chew into that resource at a fairly modest 7 percent per year rate of compounding, doubling every decade. By the year 1970, the 1 trillion had become 22 or 23 trillion and the 1700-year supply at present rates of use had become 50 years. We had used some, and of course the base was much higher, and we simply had reduced that arithmetic to the point where it was much less pleasant to look at.

Now, if we had continued that rate of compounding, as seen from the perspective of 1930, we would have exhausted the entire 1700-year supply by the year 1985. If we had taken the larger number that up until 2 years ago was used by the U.S. Geological Survey as their extrapolation of what was there, about double AGA number, it would have given us another 10 years of compounding. As those of you in the physical sciences know, in the last doubling period of exponential growth, we use a volume. In this case of gas and in the case of many biological phenomena, it would be growth equivalent to all of previous history.

When somebody blithely says, as the Federal Energy Agency did say in 1974 in conjunction with Project Independence blueprint, that we can in effect double the supply of gas in 15 years, my answer is that, that is not credible because it takes too much energy. And similarly, when I hear that there is a 1000-year supply of gas, I have to tell you that, that particular calculation is not a public one; it is a black box calculation. If you want the public calculations, you would have to go to the Geological Survey and FEA work that has been done in the last few years. You cannot make national policy based upon that set of assumptions, but upon more ascertainable assumptions, because if you are wrong and if it turns out that instead of a 1,000-year supply, there is a 3-year supply, you run the risk of wrecking the country. We have to put a stern test against these assertions that there is a conspiracy and that through maladministration we are being denied access to an enormous reserve.

COMMENT:

I guess it would seem peculiar to think that the Wall Street Journal would be the place to look for an indictment of industry.

RESPONSE: Mr. O'Leary

The Wall Street Journal believes in a market-oriented mechanism to cure the energy problem and sees that evidence as fortifying their belief. I for one wish it were so, but I spend 80 percent of my time in regulatory activities that would not be necessary if we had an orderly market in the oil and gas industry. I would much prefer to see market forces do this job for us. However, the way the world is constituted today, I do not see any immediate prospect of that.

QUESTION:

You mentioned that you are seeing a re-evaluation of water use coming about in 4 of 5 years. I would like to know when you would see the technologies being developed and how you see them relating to corporate resource development time lines?

RESPONSE: Mr. O'Leary

In the solar cell pumping activity in central New Mexico, we had to join the solar pumping, solar irrigation activity with a very well thought out conservation effort. If we did everything the way we had been doing it, clearly we could not make it on solar. Just the price of the crop would rule it out. By way of background, this part of New Mexico and adjacent Texas has historically depended upon gas for pumping, and their gas bills, of course, are going through the roof. In the Pecos Valley in Texas they have gotten so high that the farmers have simply abandoned irrigated agriculture, and the land is literally blowing away. In New Mexico we have been able to forestall that for a while, but we thought we needed a successor technology and have been working with ERDA in the development of a pilot program that would substitute solar energy for the pumping function of gas energy. Unless we were able to save about half of the water, we could not make a go of it because of prospective crop price restraint and not because of the opportunity costs with other energy sources. Consequently, those at the state agricultural school brought their water conservation technology, together with the ERDA solar technology, and I think we are going to find that water economics will play a major role in bringing about conservation. This will probably be replicated in hundreds of settings, maybe thousands, during the next couple of years as a result of the fundamental climate change that has occurred on the West Coast.

Awareness is the first tool in this: that we do not have an infinite amount of water and cannot continue to price it at a penny per ton. The limited supplies of water bear very heavily upon the future economic prospects of that part of the world, and unless we begin to use them conservatively in the same way that energy is being used conservatively, we are going to have serious trouble.

I think the whole debate over Carter's decision on plans for water development will be seriously addressed over this next 3 to 4 years and bring the argument to a head.

QUESTION:

In contrast with the philosophy you just expressed regarding availability of resources, the recent Ford Foundation-Mitre study indicated that the United States had very large quantities of uranium, sufficient, in fact, to abandon reprocessing and the breeder reactor. This has, of course, become the administration policy. Could you comment on the contrast in the two situations?

RESPONSE: Mr. O'Leary

Yes. Relative to uranium resources, I would say that oil and gas are a well-explored proposition. It has better than a 100 years of history now. Last year we completed 36,000 wells as one measure. There are all together some 600,000 producing wells in this country. And when we take a look at a leasing map of the principal oil-prone and gas-prone areas of the country, we find, as we have found with our 2 1/2 mile rule on the map that the area has been pin cushioned down to a depth of 6,000 feet. You cannot say this about deep oil and gas resources because there has not been that level of activity.

Now, contrast that with uranium. We had a brief flurry of very high activity in the late forties with regard to uranium finding. Then, uranium went into a recession and people were in a holding mode. Only in the last 3 years has there been a very substantial runup in activity. First, in 1974 and 1975 we really did not know very much about the resource. Second, our projections with regard to deployment of light water reactors were very optimistic in the early 1970's, and they have since gone. We looked at 285,000 megawatts in 1985 from the perspective of 1972. We are now looking at 121,000 megawatts of installed nuclear capacity. In the halcyon days of 1977, we were looking at 2,000 megawatts in the year 2000, and now we are looking at perhaps 350 to 550.

First, we do not know very much about this resource and, second, the demand is moving so slowly that we have time to first assess the resource and then assess alternative technologies. The President's program simply is not going to put us into a tight box. He is not saying we have infinite resources of uranium, but that we have enough to have time to contemplate more thoroughly the movement of this economy into the mixed oxide world.

QUESTION:

But don't you run the same basic risk? If you are wrong about resources, then you have a large number of plants without any resources?

RESPONSE: Mr. O'Leary

I think that risk is a real one, but in terms of the conventional appreciation of the uranium resource over the conventional appreciation of the number of reactors that are going to be deployed over the next 25 years, it is not much of a risk. Any time we get beyond our measured reserve, we have a risk, and the measured reserve of uranium in this country is now maybe 12 years. Any time we get beyond that in oil, or gas, or copper, or aluminum, we have a risk. The probability of that risk coming in uranium I think, given all the backups, is not too great. We could go to reprocessing on relatively short notice if we had to.

COMMENT:

If there is a natural gas shortage, it would appear wasteful to consume most of our natural gas for space heating or for boiler fuel. It would appear that industrial processes and agricultural uses should have priority for the future and that we should make strong efforts to discourage the use of any natural gas for either space heating or boiler fuel.

RESPONSE: Mr. O'Leary

I would agree with you on boiler fuel, and indeed, the President's program does call for a phaseout of boiler fuel use in large installations of gas by 1990. Space heating, however, is a matter of economics, If you look at the choices available to a householder, the gas priority that is now assigned him is appropriate. This is the first priority, in advance really of process use of the gas. I will refer you to an A. D. Little report that was done in 1972 in support of General Motors in one of the early curtailment cases to show the schemata for coming to that conclusion. Actually, the cost for many converters away from natural gas to something else are far, far lower, one to two orders of magnitude lower, than the cost of taking household space heating off of natural gas. That is from my perspective the economic drive of the problem.

QUESTION:

I suggest that the economics of not having enough fuel to maintain healthy economy might be much more severe if we should continue to consume this fuel for space heating in either private homes or businesses, factories, anywhere where it is avoidable.

RESPONSE: Mr. O'Leary

I think that that is a very real point. If you look, however, at the enormous concentration of natural gas usage under boilers and begin to phase that out, you get into a problem, and we have encountered this problem in a statistical sense over the last 2 months in trying to arrive at the policy that I have just touched upon briefly. You arrive at the problem not of shortages of natural gas for process use but of surpluses.

control technology bridges to the future

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OVERVIEW part II

I would like to thank John O'Leary for sharing with us today his well-balanced perspective. If there is one thing that we can conclude from what he, Secretary Schlesinger, and President Carter have been telling us for the past 5 weeks, it is that we live in a time that is fraught with risk, but also with challenge. Some among us are the pioneers. They have been to the edge of the chasm and have come back to tell us how steep the sides are and how to avoid falling down them and drowning in a river of foreign oil.

Our challenge at this critical time is to help to build the bridges that will carry us beyond the energy shortages which appear inevitable within the next two decades, and will deliver our nation and its economy safely into a future age in which changes in our economic structure, along with as yet untapped forms of energy, will sustain us.

LEAPFROGGING FROM ONE ENERGY SOURCE TO ANOTHER

The reason we need these bridges today is quite simple. It is because the past history of energy use in this nation has been characterized by leapfrogging from one major source of energy to the next. In the early days of our nation, we depended upon winds, falling water, animal power, and wood. Then came the age of steam and its more concentrated energy source, coal. Two generations later, we shifted our economic base to an even more convenient form of energy, oil, and shortly thereafter began using enormous quantities of natural gas. Thus, for the past century and a half, every other generation has brought with it a whole new, and far cleaner, source of energy. Yet, as we jumped from one energy source to the next, we either failed to build usable bridges or else burned them once we were safely across. Now it is time for us to leapfrog to other sources of energy. For a long time, we assumed that our next landing point would be even cleaner and more convenient than the last. Nuclear power was to be our next great source of energy, and perhaps the last we would ever need. So, like a frog in a lily pond, we got ready to jump. But we hesitated. The next lily pad suddenly looked smaller and much farther away, and our own pad began to shrink. That is why we need bridges firmly anchored on both shores.

As stated in the National Energy Plan, "The U.S. and the world are at the early stage of an energy transition. Previous energy transitions in the U.S. were stimulated by new technologies, such as the development of the railroad and the mass production of automobiles, which fostered the use of coal and oil, respectively. The latest transition springs from the need to adjust to scarcity and higher prices."

The role of the control technology we will discuss here today is to give us breathing room to make the transition to other forms of energy without disrupting our nation and our society. Control technology forms the bridge that will support us while we make the necessary economic and technological shifts.

CONTROL TECHNOLOGY BRIDGE

Our view of the nation's energy problems has certainly matured over the past 4 years. We have begun to realize that major economic and technological shifts take time, and that the economy and technology of a decade from now will look very much as it does today. Unfortunately, our energy supplies will not. We need the control technology bridge to give us time to develop the miracle technologies that we continue to read about almost daily—technologies such as fluidized-bed combustion in the mid-term and coal gasification, oil shale, solar, and nuclear fusion over a longer term. While these technologies are all very promising and worthy of our investment, none of them, with the possible exception of fluidized-bed combustion, will have impact of any consequence before the mid to late 1980's. That is simply the nature of technology and the time it takes to achieve significant commercial application. Until that time, we will rapidly shift to burning coal in the familiar, conventional industrial

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and utility boilers, and will apply the best available control technologies to avoid serious environmental problems.

A power plant is a very expensive piece of capital equipment. It is expected to last 30, 40, 50 years, or more, and to give reliable service for that period. Hence, even if a totally new technology were developed and available for commercial application within a decade, we would continue well beyond the turn of the century to generate most of our utility and industrial power through conventional means. And, from an environmental perspective, we cannot last that long without the kinds of pollution control technologies that we will discuss today.

A "TECHNOLOGICAL FIX"

The role of our control technologies as a bridge to the future of our energy supply is now becoming clear. Environmental control technology—known to science policy buffs as a "technological fix"—will, combined with energy conservation, assure us safe passage from today to 1985 and beyond.

The American people are gradually becoming aware of the scope and uses of environmental control technology. To most people it means a piece of equipment or an installation added to a system to decrease the system's pollution emissions. Most motorists are aware that new cars are equipped with catalytic converters to cut down automobile exhausts and thus reduce urban smog. City and townspeople are aware of the problems their communities are having in handling sewage and refuse. They know that their communities are building or improving sewage treatment plants or are trying to locate new land disposal sites for solid wastes. Many people know that their local utilities and industries have had to put cleanup devices on their stacks and discharge pipes and that the air and water in their area is cleaner than it was a short time ago.

National opinion polls show a high degree of awareness and approval of measures to protect public health and safety. These same polls also indicate a strong willingness to accept personal sacrifices in order to continue these improvements. Recent surveys have even shown an increase in the level of public support for these measures despite nagging energy problems, industrial siting difficulties, and a general concern about excessive government regulation.

BEST AVAILABLE TECHNOLOGY

During the past decade, there has been a subtle but definite shift in our approach to environmental protection. We have moved steadily away from doing barely enough to protect public health and safety and toward doing as much as is practicable. In other words, we are beginning to use as much control technology as we can economically tolerate in order to have some margin of safety and flexibility for the future. In 1970, the modified Clean Air Act established the requirement for New Source Performance Standards, necessitating the best commercially demonstrated pollution control equipment for certain air pollutants on all major new industrial facilities. In 1972, Amendments to the Federal Water Pollution Control Act established a system of effluent guidelines for the Best Practical Technology (BPT) and Best Available Technology (BAT) for control of the most common water pollutants for each major industrial category. Last year the Environmental Protection Agency was ordered by a U.S. district court to apply, on an accelerated schedule, Best Available Technology standards to the control of 65 toxic materials in the wastewaters from 21 priority industries. Finally, just over a week ago the House of Representatives voted to require best available control technology on all new utility boilers in order to minimize the atmospheric loading of sulfur oxides and their by-products, to increase the use of locally available coals, and to give some room for industrial growth in most parts of the country.

In short, we are beginning to control air and water pollution wherever and whenever it can be controlled. And the scientific information on health and ecological effects of such pollution has consistently supported the wisdom of this trend.

DOOMSAYERS' PREDICTIONS CONTRADICTED

Where, then, will this lead the economy? Contrary to the doomsayers' predictions, we will be in pretty good shape. Not even the BAT provision of the House amendments to the Clean Air Act will represent an extreme economic burden. Under the worst-case assumption that each new coal-fired power plant will need to scrub all of its stack gases, the increased cost to utilities between now and 1985 is estimated to be $19.3 billion more than the $155 billion the utilities will need for plant construction without pollution control equipment. Thus, air pollution controls will cost slightly more than 12 percent of the capital investment that the utilities will be making in coal-fired boilers over that time period. The direct increase in an average residential electric bill as a result of Federal pollution control regulations will be approximately $1.80 per month in 1980 and $2.80 per month in 1985. These impacts represent 5.3 and 6.6 percent increases, respectively.

Macro-economic projections indicate that in 1977 all of industry will be investing a maximum of 3½ percent of total private plant and equipment expenditures in pollution control equipment. After 1977 the percentage of total investment allocated to pollution control equipment is projected to decline. The gross investment for all industry for stationary-source air pollution control during the period of 1976 through 1983 will be approximately $21.6 billion; for water pollution control it will be $30.7 billion. Again, a significant, but not overwhelming, proportion of total capital investment.

From the point of view of our national economy, the GNP will be only ½ of 1 percent less in 1985 with these pollution control investments than it would have been without them. And think of how much the quality of our lives, indeed our very health, would have deteriorated over the coming decade without these investments. It is a small price to pay.

OUR ONLY BRIDGE TO AN UNCERTAIN FUTURE

Although we recognize the importance of the environmental protection afforded by these investments in control technology, there still linger ambivalent feelings about environmental control technologies. Do we really need them? Aren't there other ways of achieving the same objectives? Aren't there breakthroughs waiting just around the corner which will obviate the need for our control technologies? Or, if we shut our eyes tight and wish very hard, won't the problems go away? My answer is that control technologies are our bridge, and our only bridge, into an uncertain future.

As the President's National Energy Plan points out, the main components of our energy supply over the next several decades are coal, light water nuclear reactors, and dwindling supplies of oil and natural gas. These, taken with strong doses of conservation, may get us to 1985 or 1990 without our becoming intolerably dependent on imported oil.

Those of you who are familiar with nuclear power reactors will appreciate the use of light-water reactors as an example of exhaustive control technology efforts. Well before safety-oriented thinking had begun to infiltrate into regulation of other industrial activities, the old Atomic Energy Commission required radioactive emissions from operating reactors to be kept "as low as practicable." This translated into emissions control 100 to 1,000 times more stringent than necessitated by the then-applicable health standards. While adequate attention was probably not focused on the entire fuel reprocessing and waste disposal portion of the nuclear fuel cycle, control requirements for power reactors set some important, and largely unmatched, precedents for regulation of energy facilities. Without the public confidence that doing the very best inspires, the role of light-water reactors in carrying part of the energy load over the next decade would be highly questionable.

COAL AS AN ENERGY SOURCE QUESTIONED

But what of coal and its role as the fuel to take up some of the slack between even a dampened demand and limited domestic supplies? Doesn't the expansion of coal production and use from 0.7 billion tons in 1977 to 1.1 billion tons in 1985—as called for in the Energy Plan—mean a significant degradation of our environment? Can we dramatically expand our mining of coal without devastating environmental repercussions? And, once mined, can we burn it at an acceptable environmental price?

The answers to these key questions would be a resounding no if it were not for the control technologies developed over the past decade and, in some cases, still being developed. Without proven techniques to control the air pollutants and the mining damages, we would have used up our options. The work that many of you have done, and continue to do, in these areas has, in the nick of time, provided this country with an escape route over some very dangerous, oil-slicked water.

The key technologies that will allow us to expand dramatically our domestic use of coal are those which control sulfur oxides, nitrogen oxides, fine particles, and mining-related pollution. Those problems related to sulfur pollution control and mining-related controls have been most rigorously addressed, and we are within sight of having solved most of the major aspects of both these problems. This is one of the proudest achievements of the Interagency Program to date.

The other two pollution types—nitrogen oxides and fine particles—are now being rigorously investigated, and some truly promising potential solutions are being developed. The priority of these efforts is clearly asserted by the National Energy Plan, which states, "Coal will meet the greatest portion of increased U.S. energy needs. A comprehensive coal research and development program is high priority. The program should focus on meeting environmental requirements more effectively and economically, and should seek to expand the substitution of coal for natural gas and petroleum products. In the short term," the Plan continues, "most coal will continue to be burned directly. Hence, the highest immediate priority (I repeat, the highest immediate priority) is the development of more effective, economical methods to meet air pollution control standards."

NO COMPROMISE ON ENVIRONMENTAL GOALS

Hence, there is no longer any question whether, or how far, we will compromise our environmental goals to achieve expanded energy resources. There will be no compromise. There will be no artificial dichotomy of energy needs versus environment. We will have the energy we need, and it will not be at the cost of our property, our health, or our sense of aesthetics. This is our national energy plan.

Since late in 1974, the Interagency Energy/Environment R&D Program has been building the foundation upon which such a national energy plan could be built. Using the leverage which a $100 million per year budget gave us, we began perfecting the control technologies necessary to meet our dual goals of increased coal use and environmental protection. Since the energy crisis was an immediate one, our focus in the control technology portion of the program was on the near and mid-term.

With this near and mid-term focus in mind, we went about identifying and developing controls for the four major problem areas mentioned earlier—sulfur oxides, nitrogen oxides, fine particles, and mining disruption. While our technology bridge to the future over each of these problems is far from perfect, at least we can now see the other shore.

Before I become too involved in describing out Interagency Program as it relates to today's energy-related pollution controls, I would like to make note that we are also looking into the future to assure that advanced technologies, when they do become commercially applied, do not pose their own set of environmental hazards. It would be a distorted perspective to limit our attention to solving today's problems while allowing tomorrow's to grow unchecked. For example, in parallel with efforts by ERDA to develop coal-fired fluidized-bed combustors for heat, steam, and power generation, EPA is conducting a complete environmental characterization of the process. Our goal is to identify early, and help to avoid, any potential environmental problems that may be associated with this very promising technology. Later today you will be given a description of the scope and preliminary findings of this environmental assessment.

POSSIBLE LONG-TERM TECHNOLOGIES

Other possibly longer-term technologies offering significant promise are those known collectively as synthetic fuels. These fuels, while offering solutions to problems associated with the use of coal, present some new, and potentially serious, environmental problems. Working with ERDA, we are developing a coordinated effort to assure the exhaustive monitoring of this country's early synthetic fuels plants. These plants are scheduled to become operational within the next few years. Such multi-agency data acquisition and analysis coordination will help assure that the best controls are available at the lowest costs and with the greatest speed to meet our Nation's need for alternative supplies of liquid and gaseous fuels. The details on these efforts will be presented at a later session today.

Nor does the Interagency Program ignore potential new sources of energy. We have played a key role in sponsoring the development, to commercial scale, of systems to extract useful energy from urban and industrial wastes. Co-firing of wastes with coal has been supported at both Ames, Iowa, and St. Louis, Missouri. Sampling of the pollutant streams from these demonstrations indicates that particulate emissions increase while SO_x and NO_x emissions decrease. You will hear more on this during a later session. We are now testing a densified fuel produced from solid waste in a small coal-fired stoker boiler near Hagerstown, Maryland. If successful, this approach could extend to many more American cities the applicability of co-firing wastes.

Finally, we are also conducting important activities in such areas as geothermal power and oil-shale extraction and processing. We have, for example, recently published a report of investigations on the state of knowledge with regard to oil-shale developments and their associated environmental implications. We will soon publish a report providing guidance to the emerging geothermal industry by specifiying design targets for pollution control equipment.

COAL MINING PROBLEMS IN THE EAST AND THE WEST

The problems of coal mining, on the other hand, have been with us for a long time and are still here today. For purposes of simplicity, these problems can be summarized as falling into two types. The first type, characterized by too much water, is located in the East. The second, characterized by too little water, is located in the West.

More than 85 percent of the Nation's coal is mined in the eastern part of the country, and more than half of that comes from underground mines. The control of water pollution from underground mines continues to be one of our most difficult problems. Although mine drainage can be treated while the mine is active, treatment becomes uneconomical upon shutdown. Emphasis here is on careful premining planning and postmining sealing.

Great strides have been made in the past 10 years to reduce the environmental impacts of surface mining in the East. Several new mining and reclamation methods, with picturesque names such as head-of-hollow fill, mountain-top removal, and haul back, have been developed in the past few years. We are examining the environmental advantages of these second-generation techniques which we feel will minimize the environmental problems associated with surface mining.

Participating in the Interagency Program's mining research activities are five other agencies. For example, later in today's conference you will hear of the efforts we are cosponsoring with the Department of Agriculture's Agricultural Research Service to determine the adaptability of various plant species to different types of mining spoils and climates.

In response to accelerated coal development, we have placed more emphasis on coal mining pollution control, especially in the West, where we have the farthest to go. We have both short- and long-term projects, ranging from assessing the probable impact

of mining to determining the effectiveness of various reclamation practices. Information from our control technology program for mining in the East is well enough along to be compiled into a pollution planning mining manual which will be published within a month. This document stresses premining planning so that controls can be designed into the mining operation from the outset. Later today you will also be hearing about the U.S. Forest Service's efforts to predict, and therefore help control, the impacts of mine support facilities, including access and haul roads. In some instances, these support roads can have a more destructive and more lasting impact than does the mine itself.

WESTERN COAL DEVELOPMENT

Coal areas of the arid and semiarid West pose a different set of problems which have not yet been as fully investigated as have the problems of eastern coal. Western coal fields contain more than 60 percent of the strippable coal reserves in the U.S.. Much of it is low-sulfur. If we are to achieve our goal of nearly doubling our coal production by 1985, at least 350 million of our projected 1.2 billion tons of coal produced will probably come from western coal fields. Western production will increase by a factor of four during that period.

LACK OF WATER

Many of the difficulties in developing western coal reserves are related to water—its absence or location. For example, coal seams are generally aquifers—underground storage and transportation zones for fresh water. Mining may change the distribution of ground water and disrupt the aquifer. In an area as dependent on a reliable supply of fresh water as is the West, you can imagine the magnitude of this problem.

REVEGETATION

An associated difficulty in reclaiming strip-mined western lands is revegetation. Climatic conditions are extreme. About 75 percent of the western coal fields receive less than 20 inches of precipitation annually. In addition, seasonal temperatures may vary from 50 degrees below zero to 120 degrees above zero. There are only short frost-free periods, and topsoil is inadequate. Western coal lies beneath a layer of geologically young material which is subject to excessive erosion. Flash flooding and wind erosion result not only in loss of valuable soil but also in air pollution problems for vast areas. Last summer's drought, for example, resulted in a dust cloud which crossed the Nation and was last seen out over the Atlantic Ocean on its way to Europe.

Many of the most promising solutions to our coal-mining environmental constraints are not technological, *per se*, but are rather in the application of existing technology in a more careful and sensitive manner. Only by careful premining planning is it possible to avoid irreversible mistakes. Planning investigations include range inventories, soil surveys, grazing pattern definition, archeological review, and groundwater and overburden analysis. Such studies serve as a basis for erosion control and rehabilitation design and directly influence the choice of mining techniques and equipment. Diligent use of these evolving methods will allow the prediction and control of most extraction and rehabilitation problems.

In addition to a judicious approach to mine planning, several Interagency Program projects are investigating novel and promising methods of rehabilitating mined lands. Perhaps the most intriguing of these methods has the potential for solving two problems at once—rehabilitating mined lands and disposing of urban sewage sludge. Such projects involve close cooperation between Federal, State, and local officials, along with support from USDA's Soil Conservation Service. Though we make no claims to having proved that all of our mined areas can be revived while solving all of our sludge disposal problems, it is clear that this procedure can and does work for specific, suitable applications.

TRIAD AIR POLLUTANTS— SO_X, NO_X, PARTICULATES

Now that we have discussed the bridges for those environmental problems caused by coal mining, let us look at our three major remaining problem areas—the triad of air pollutants known as SO_X, NO_X, and particulates. Coal combustion produces a very large portion of these air pollutants. And all of these pollutants are, to a greater or lesser degree, hazards to both human health and agricultural crops. During fiscal years 1975 and 1976, the Interagency Program concentrated much of its resources and attention on developing control technology for one of these pollutants, sulfur oxide. Out of a program of close cooperation with Tennessee Valley Authority and private utilities have come many important developments for the flue gas desulfurization systems or "scrubbers" that are commercially available today. I will discuss this process in a minute, but let me give you first a few statistics on its growing acceptance.

In the early days of flue gas desulfurization technology, EPA and the utilities did not always see eye-to-eye. But times have changed dramatically. Our latest figures show that 51 electric power companies have installed, are installing, or are planning to install some 122 scrubber systems. When completed, these 122 scrubbers will control the SO_2 emissions from a power-generating capacity of nearly 50,000 megawatts. Such an achievement will take us more than half-way towards meeting the goal of 90,000 megawatts of scrubber-controlled generation that EPA estimates will be needed to meet SO_2 emission standards by late 1980. From Alabama to Arizona and from New England to Nevada the flue gas scrubber has come of age. And not a moment too soon.

There are now more than a dozen reputable firms selling various types of scrubbers, and most of these units can remove 80 percent or more of the sulfur oxides from power plant emissions. But it wasn't always that way. The history of the flue gas desulfurization scrubber is a long and colorful one. The first scrubber was installed on an electric generating plant in the mid-1930's in London. This Fullam unit used both lime and limestone. It successfully met and solved many of the same problems that we encountered 35 years later when the effort was interrupted by World War II. It was shut down not because it didn't work or because it caused too much waste or used up essential war material. It was closed because the steam plume from the scrubber made a perfect target for the German bombers.

FIRST SCRUBBERS NOT PROMISING

Our first experiences in this country were not as promising. The first two of our units were the victims of haste. The pilot units were not tested long enough to solve all of the problems, and upon going to full scale, we encountered some novel problems. The most picturesque of these was during an early test of a unit having a marble bed. When turned on, the unit proved to be more effective at producing concrete than at reducing sulfur oxides. By the time the problem was discovered, we had replaced the marble bed with a concrete one, and it took an army of picks and hammers to clean out the unit's interior. But we persisted, driven by the knowledge that sulfur oxides are among the most ubiquitous and harmful air pollutants in this country, and that they cause untold damage to human health, vegetation, buildings, and materials.

TWO BASIC TYPES OF SCRUBBERS

There are two basic types of scrubbers available today. The first produces a sludge which must be disposed of; the second produces a by-product which can be sold. Among the sludge-producing systems, the lime and limestone scrubbers are by far the most common. These units make up approximately 75 percent of the 122 scrubbers installed or scheduled for installation. The other major sludge-producing system is the dual alkali system. Just one month ago we completed the first phase of a demonstration of this technology in Louisville, Kentucky. Based upon testing of a prototype unit installed in 1975 at the 20-megawatt test facility belonging to Gulf Power Company, the Louisville system is scheduled to start operation during 1978. The system is being installed on an existing 280-megawatt coal-fired power plant. The testing of the prototype was extremely successful, showing sulfur dioxide removal rates as high as 99 percent. Perhaps the greatest advantage of this technology, however, is its low power needs. The dual alkali process is expected to consume less than 1.2 percent of the energy generated by the power plant. This is less than half of the energy required by other flue gas desulfurization processes now being installed.

SLUDGE-PRODUCING SCRUBBERS

In addition to perfecting existing systems and investigating new ones, the Interagency Program is also conducting extensive investigations into the most effective means of disposing of the wastes from sludge-producing scrubbers. Working, again, in cooperation with the Tennessee Valley Authority, we have characterized and quantified many aspects of scrubber sludge. The sludge itself, contrary to popular belief, is comparable to the other wastes from the ash- and particle-collection units which are totally independent of the scrubbers.

However, scrubber sludge does pose some knotty problems. Disposal costs can reach 20 percent of the cost of the operating system itself. The sludge is wet with a consistency half-way between toothpaste and blue cheese, and its color is dirty grey. Prolonged storage of sludge in ponds poses potential water pollution hazards. These hazards can be reduced by various stabilization processes which reduce the permeability and solubility of the sludge. In addition, again with TVA's involvement, we are investigating more efficient and economical equipment for removing the water from the sludge and for reducing the volume of water by oxidation of wastes into gypsum.

Another solution to the problem of disposing of sludge from scrubber systems is to provide systems that produce a by-product which can be sold instead of dumped. We are presently in the start-up phase of a demonstration of a sulfur-producing system. Constructed at a 115-megawatt facility owned by the Northern Indiana Public Service Company, this system will produce sulfur acid or, given the proper reactant, elemental sulfur. At the Indiana site we are testing the process on coal since it has already been proven on a commercial scale in Japan for use with oil-fired boilers.

NONSLUDGE PRODUCING SYSTEM

A little farther down the road is another nonsludge-producing system—the aqueous carbonate process. This process has been proven in limited pilot scale testing and is currently in the design phase for a demonstration to be conducted on a 100-megawatt facility at a Niagara Mohawk Plant in New York. The process has great potential payout. It is an inherently simple process which produces elemental sulfur as a by-product at costs which may be comparable to limestone scrubbing.

A nontechnological alternative to scrubbers for controlling the sulfur emissions from coal-fired power plants is to burn low-sulfur coal in the first place. Nearly 90 percent of the low-sulfur coal reserves are located in the western coal fields. These are, unfortunately, far removed from where the coal is most needed; east of the Mississippi. The energy and economic costs of transporting the coal from the fields to plants in the East are comparable to the costs of using scrubbers with local eastern high-sulfur coals. Also, any tightening of the present sulfur regulations would severely restrict the number of different coals which could be directly burned without controls. As if these were not significant problems, the burning of low-sulfur western coals creates difficulties in another area—that of fly ash and particulate control.

COAL CLEANING

If we cannot dig up enough low-sulfur coal to meet our needs, why can't we remove the sulfur from higher-sulfur coal before we burn it? The answer is, we can, within certain limits. Coal cleaning is a rather straightforward process. It involves crushing the coal and using the differences in density between coal and its contaminants to separate the two. The process has been in use for years to supply high-quality, low-ash coal to the metallurgical industry, but it has yet to be applied to meeting coal pollution standards.

From its inauguration in late 1974, the Interagency Program has been instrumental in keeping the coal-cleaning option open. Working with the Bureau of Mines, we supported authoritative studies which have characterized the cleanability of nearly 500 different types of domestically mined coal. We have determined that physical coal cleaning is limited in its applicability to certain highly cleanable coals. However, it does have one major advantage—it is the least expensive way of removing a given portion of sulfur from coal. I am aware of no other technology—neither present-generation such as flue gas desulfurization nor emerging-process such as fluidized-bed combustion—which can remove a significant amount of sulfur as economically.

We are currently involved in a pioneering effort with the GPU/PENNELEC effort in Homer City, Pennsylvania, which will be the first full-scale application of coal cleaning to meet air pollution standards. The EPA, along with the Bureau of Mines, will be conducting the environmental monitoring and assessment of this $50 million private installation.

POTENTIAL BENEFIT OF COAL CLEANING

One important potential benefit of coal cleaning is to provide an optional way of controlling sulfur oxide emissions from small boilers, in the size range of 25 megawatts or less. Presently such boilers, if shifted to coal combustion, have very few options with regard to sulfur emissions control. Another scheme for utilizing low-cost coal cleaning would be to clean the coal as well as possible for the given coal and then burn the coal and subject only a portion of the flue gas to scrubbing. The portion of flue gas not scrubbed can then be used to reheat the cooled, scrubbed gases by blending the two gas streams together downstream of the scrubber. This combination of technologies can lead to substantial cost and energy savings in these and other applications.

CHEMICAL COAL CLEANING

In addition to physical coal cleaning, which removes only a limited portion of the sulfur in the coal, we are also investigating alternative processes that promise advances in either efficiency or economics. Chemical coal cleaning processes, for example, are in the development stages. We have investigated or are investigating various processes such as froth flotation, microwave treatment, high-intensity magnetic separation, and various leaching processes. Major projects are in progress to develop performance and cost data on commercially available coal and mineral-cleaning equipment which can be used for desulfurization. The results of these and related studies will prove an extremely valuable counterpoint to the developing flue gas cleaning technologies. Both of these are key supports to our bridge to a cleaner, more energy-independent future.

PARTICULATE CONTROL PROBLEMS

Turning now to the second of our three coal-related air pollution problems, particulate matter, it is useful to recall that the particulate control problem has been solved several times before. In controlling particles from power plants burning most Appalachian or Midwestern coals, the modern, high-efficiency electrostatic precipitators (ESP's) have provided a fully adequate solution for several decades. However, new problems have emerged, requiring new solutions.

First, the increased use of lower-cost, lower-sulfur and higher-ash-containing Western coals has revealed a serious shortcoming in electrostatic precipitators as they are now designed. Their effectiveness drops if the ash has a high resistivity, which is typical of the ash from most western coals. Furthermore, with lower sulfur content in these coals, less sulfur trioxide is produced in the boiler, also leading to degraded performance by the precipitator. And a few years down the road are the low-sulfur, low-ash coal-derived fuels which, it appears, may cause the precipitators to behave similarly.

Second, health-effects research has shown that the fine particles (smaller than 3 microns) present a more serious health threat because these smaller particles can penetrate deep into the lungs. While the role of fine particles emitted from power plants in atmospheric pollution chemistry is not completely understood, there is increasing concern about the hazards presented by directly emitted fine particles as well as those in the atmosphere. Since most of the heavier particles are already removed by conventional electrostatic percipitators, there is considerable pressure to improve the efficiency of cleanup devices to capture more of the fine particles.

Third, the President's Energy Plan places strong emphasis on increased coal combustion, especially in the industrial and utility sectors. Since most industrial boilers are, and will continue to be, located in or near urban, industrialized areas, it is crucial that particle control in these generally polluted areas be given top priority. Without stringent control of these sources, many Americans would be exposed to higher levels of atmospheric particulates.

Fourth, and finally, the contribution of fine particulates to the creation of hazy conditions, especially in the West, is becoming more recognized. To protect visibility, a number of Western States have imposed or are considering tougher particulate control standards. This is an important driving force for improved control, again for Western coals.

In the following session, you will hear about the efforts to understand more completely and to improve the performance of ESP's, wet scrubbers, and fabric filters (baghouses) in capturing fine particles. Our efforts to restore the high-efficiency performance of electrostatic precipitators when used to capture high-resistivity fly ash through various conditioning techniques will be described. These techniques include ionization of the flue gases before they go into the ESP and injection of various chemical conditioning agents into the gases.

Baghouses and wet scrubbers appear to be attractive alternatives to ESP's in some applications. Because of their uniformly high efficiency in removing fine particles and their insensitivity to ash resistivity, baghouses appear to have potentially widespread application in the West. It also appears that some of the sulfur dioxide can be captured by injecting powered absorbent into the baghouse along with the stack gases. We hope this approach can be tested on a full-scale utility boiler in the West.

You will also hear about our work on improving the capability of wet scrubbers to capture fine particles. The use of condensing water vapor within the scrubbers to help to capture the fine ash particles will be discussed. These improved particle cleanup systems will receive an important boost in the next fiscal year through increased R&D funding. They represent another important section of the technological bridge to allow the burning of more coal while minimizing air pollution.

NO_x POLLUTION

The third of our troublesome trio of pollutants—nitrogen oxides—may present the most serious air pollution control challenge during the next several decades. Approximately half of the NO_x emissions in the United States comes from stationary combustion sources, and most of the rest comes from automobiles. Increased coal combustion will significantly increase NO_x emissions at the same time that we are encountering difficulty in controlling these emissions from cars. This is a frightening development. Health-effects research is now showing a more pronounced effect than was expected in humans exposed even for short periods to high NO_x concentrations. This so-called dose-rate effect was not previously appreciated. The role of NO_x in photochemical smog has been known for years. Hence, the prospect of significant to massive increases in NO_x emissions is extremely disturbing.

With the delay in implementing NO_x controls for automobiles recently voted in the House of Representatives, there is increased pressure for NO_x control in power plants and industrial boilers. But it won't be easy. (With the best available control practices, coal-fired boilers emit three to four times as much NO_x as does a comparable gas or oil-fired boiler, and NO_x control in coal-fired boilers lags considerably behind that for boilers burning other fossil fuels.)

METHOD FOR NO_x CONTROL

But the horizon is not totally bleak. The only method we can now count on for NO_x control is combustion modification, which uses changes in the combustion conditions within the boiler to minimize high-temperature fixation of atmospheric nitrogen with oxygen. In current coal-fired power plants, combustion modification can reduce the NO_x emissions by only 40 to 50 percent. In addition, there are serious questions about the effect of these modifications on the long-term operation of the boiler. You will hear about our efforts to see if the combustion changes lead to corrosion effects within the boiler. If operational methods are successful in minimizing the corrosion in the boiler, then at least we can count on restricting the increases in NO_x emissions as we convert much of our industrial heat capacity to coal.

JAPANESE DEVELOPMENTS

Much more promising, though, is the possibility that really significant breakthroughs in NO_x control may be possible. In Japan, for example, success with NO_x scrubbers on oil-fired boilers has suggested that such devices could be adapted to coal-fired boilers. Though we are closely examining the Japanese developments, it appears to be both expensive and technologically difficult to use such a scrubbing system on coal plants in the United States. Technology and cost aside, there is something quite unaesthetic about having a NO_x scrubber stuck onto the end of a SO_x scrubber, which is in turn attached to an electrostatic precipitator, which is connected to the boiler. So we are continuing to concentrate on modifications to the combustion process.

ADVANCED BURNER DESIGNS

You will also hear about our efforts to develop advanced burner designs which may reduce NO_x emissions by another two-thirds, yielding a total NO_x control of 80 to 90 percent. Advanced burners, along with the staged combustion approach now being investigated by the Electric Power Research Institute, may represent the breakthroughs required to check the otherwise burgeoning NO_x emissions. We are also requesting additional R&D resources in order to accelerate and expand this important work during the next fiscal year. This work is the most exciting I have seen in my 4 years of close association with the air pollution control programs – posing the grestest challenges and promising the greatest payoff.

PROSPECTS FOR CONTROLLING NO_x

To put this potential in perspective, such control levels would reduce NO_x emissions from pulverized coal burners to levels at or below those expected from fluidized-bed combustors. These combustors have long been held out as the only hope for reducing NO_x emissions. Since many of the industry experts with whom I have talked feel that pulverized coal boilers will be around through the end of this century and well into the next, I am exceedingly pleased that there are at least prospects for controlling the nitrogen oxides from these boilers. Through R&D efforts such as these, we are building new bridges to the future, not just shoring up old spans.

STEPHEN J. GAGE

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achieving compatibility between energy and environmental goals: program perspectives

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OVERVIEW part III

It is becoming increasingly evident that this is the year the Federal Government must pull together a coherent national policy on energy, the environment, and the relationship between the two. The fact that the Interagency Energy/Environment R&D Program has been in existence since 1975 has not meant, despite a lot of successful projects, that we as a nation have had a clear, comprehensive energy/environment policy.

NATIONAL ENERGY POLICY

Somehow our nation has managed to limp along for years as the only major industrialized country in the world without such a national policy on energy, let alone one which spells out the proper relationship between energy and environmental needs. One predictable result of this failing came this past winter when the country found itself running short of fuel and forced to close schools and factories and to lower thermostats to 65° F. That experience seemed to provide the incentive needed to wake us up so we could finally start working toward a consensus for national action.

That consensus for action is now taking shape as the complete, comprehensive national energy policy that President Carter outlined before a joint session of Congress. While the working details remain to be established and refined by Congress and the Administration, the main thrust is clear: To reduce our dependence on foreign oil and diminishing gas supplies, accelerated production of domestic energy resources will be strongly encouraged. While the President also stressed conservation and future application and expansion of solar and geothermal technology, increased production of fossil fuels will clearly be the core of our energy policy in the near term.

COAL-ORIENTED ENERGY POLICY

What increased production of fossil fuels really means, to a large extent, is mining and using more of our abundant coal supplies. The coal will be burned in many utility and industrial boilers which now burn oil and gas, and it will also be processed into clean-burning synthetic liquids and gases. Since coal accounts for something like 90 percent of our fossil fuel reserves but at present provides only 18 percent of our energy, a coal-oriented energy policy makes good sense.

The good news is, we are getting a national energy policy. But there could also be some bad news. Since the energy policy means expanded coal use, some severe health and environmental impacts could result from that expanded use. Because coal contains impurities, it emits pollutants to the air, water, and land when it is mined, when it is stored, when it is cleaned, when it is processed for conversion to liquids or gas, and when it is burned directly to produce energy. The potential pollutants from coal processes include virtually every one for which we have set health and environmental standards, and probably hundreds for which we will need to set standards.

President Carter and his energy advisers are aware of the tremendous potential for environmental damage inherent in a large scale coal development program. They also know what has been achieved and needs to be achieved on the side of environmental protection. And they know that a clear majority of the American people approve of measures taken to protect their environment and to keep their air and water safe and clean.

Yesterday, in the first half of this 2-day conference, you heard and discussed a number of presentations on the control technologies being developed for all energy processes and uses. The main emphasis, not surprisingly, was on controls that would allow increased use of coal in ways which will meet established or anticipated environmental standards. The control technologies ranged from improved mining and

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reclamation, through coal cleaning and waste disposal, advanced systems for combustion modification and conversion, pollution-free synthetic fuels, and finally to the latest schemes for cleaning stack gases when coal is burned directly as boiler fuel. This control technology R&D part of the Interagency Energy/Environment Program is substantial. Besides taking up half of this conference, it involves more than half (actually about 57 percent) of the Program's annual R&D funding.

This naturally gives rise to the question, what is the other half of the Program concerned with? My job this morning is to answer this question.

We know what the energy problems are, and we have a good indication, in the national energy policy, of how we are going to solve those problems. We need to and will produce and use more domestic resources, mainly coal. We also know, at least in broad terms, what our environmental problems are and how to solve them. Energy production and use, especially wilh coal, causes environmental disruption and pollutant emissions, and technologies will have to be found to control them.

HEALTH AND ENVIRONMENTAL EFFECTS R&D

So where does the other half of the R&D budget go? The answer, of course, is R&D into the health and environmental effects of energy development. This health and environmental effects research is, as it should be, an equal partner to the control technology program in making sure that we can have our energy and an acceptable environment too. We have to measure pollutants and understand something of their transport before we can design control systems to eliminate their threat. And even before that, it is essential to know whether, how, and to what degree a substance is a threat to health or ecological systems. Finally, all of the potential health and environmental effects need to be understood in an integrated perspective. As Russell Peterson, Chairman of the Council on Environmental Quality, pointed out at last year's conference, ecosystems are not affected by one disruption or one pollutant at a time or in a vacuum. Effects have to be understood in terms of cumulative impact on all areas of the environment.

A PRECONDITION FOR ENERGY DEVELOPMENT

Before going any further with what constitutes health and environmental effects research, and what the role of that research is in relation to energy and control technology development, I want to make very clear that health and environmental effects research is not. First of all, environmental researchers are protagonists for environmental protection, but that must not mean that we are antagonistic to energy development, in some sort of battle in which either energy or the environment has to lose. The title Environmental Protection Agency suggests that environmental concerns are more important than energy concerns in our outlook, but this does not mean environmental concern to the exclusion of energy development, any more than ERDA

stands for the full speed ahead development of energy, and the environment be damned. Energy needs and environmental needs don't have to be incompatible. Our new Administrator at EPA, Douglas Costle, stated the position clearly in his confirmation hearings before the Senate when he said: "For too long, environmental concern has been portrayed as an obstacle to energy development. This Administration, in contrast, believes that environmental protection is not an obstacle but merely a necessary pre-condition for energy development."[*]

A quote from him after he became Administrator puts it even more plainly: "The truth is, we can have both (energy development and environmental protection). People want to make sure that when you go to coal you protect the public health."[†]

To be fair about the whole thing, we probably should hear something from the other side. We at EPA have not always agreed with the American Electric Power Association, but we cannot quarrel with this statement from one of their recent full-page newspaper ads: "If we are to live in a better America, we must recognize that the carefully planned construction of environmentally sound power units which will insure an adequate supply of energy in the years ahead is crucial to the solution of our energy peril."[§]

ENVIRONMENTALLY SAFE ENERGY

Our emphasis in the health and environmental effects half of the program is on making sure that energy development proceeds in environmentally safe and sound ways, but at the same time we do concur in the critical need for increasing domestic energy development. That is how I see the evolving consensus of the American people, the Congress, the Administration, and the courts. Health and environmental effects R&D has to proceed with each phase of energy development so that need for controls can be identified and included as the energy development proceeds. This wary kind of partnership is the way to ensure that energy resources can be developed as rapidly as possible, unhindered by lawsuits and costly delays, and that human health and environmental values will be protected.

Having stated what the role of health and environmental effects research is not, I will now tell you briefly what it is. I touched on some of the things we do to allow energy development to proceed as rapidly as possible. We identify and monitor pollutants that are a threat to health and the environment, determine the physical and chemical changes that occur as pollutants are transported throughout the environment, and document, with scientifically defensible data, the real threat to human health or to ecological systems.

This research leads to establishment of environmental standards wherever they are needed, and it also points out the need for application or development of the most effective control technology to take care of any problem. Environmental research, of course, does not end with the promulgation of a standard and installation of a pollution control device. It must be continuous because there is a lot we don't yet know about the threats to human health and the environment from energy development processes. We are not talking about snapdragons and snail darters: we are talking about contamination of aquifers in states where water is dearer than oil, and in the longer term we are talking about carcinogens that, if we don't detect and control them now, will be crippling and killing human beings in 10 to 20 years. Human life, as well as billions of dollars in control technology, is in the balance. With those stakes, we in health and environmental effects research have to do the best we can to provide the best obtainable information on the threats that exist and how they can best be minimized or eradicated.

NATIONAL CONSCIOUSNESS FOR ENVIRONMENTAL PROTECTION

President Carter has gone to great lengths, both in the campaign and in his first 100-plus days on the job, to stress the importance of openness and honesty in government actions. In all openness and honesty, environmental actions in the past have not always been based on hard scientific evidence. Some actions have been taken because the need to act, both because of the potential threat and because of Federal law, has been imperative. Research on health and environmental effects has often lagged behind a perceived awareness of the imminent threat from pollution and a collective determination to do something about it. If we haven't quite arrived yet, we are at least well on our way to developing a national consciousness of what we need in the way of environmental protection, and how it has to be balanced against the need for energy. That consciousness makes the job a little easier.

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[*] Statement to the Senate Environment and Public Works Committee, March 2, 1977.
[†] Interview published in the *Washington Post*, April 12, 1977.
[§] American Electric Power advertisement appearing in the *Washington Post*, April 12, 1977.

If public awareness of environmental threats makes environmental protection a little easier, it also places on us a heavy burden of responsibility. We have to be sure we are doing the best job we can to find out, as precisely as we can: what substances are hazardous; how we can detect and measure them; at what levels they are a biological threat; how they act in the environment; and in what manner they can best be controlled or eliminated. We do these things well, not just for the unassailable purpose of saving lives and the environment, but also for good economic and practical reasons. Domestic energy development can proceed only as fast as we can either certify that it's safe, or provide the knowledge for development of environmental safeguards. That is the role of health and environmental effects research in the Interagency Energy/Environment R&D Program.

At last year's conference, we told you what was planned or what was just getting started in the Interagency Program. Today we are able to tell you the results of health and environmental effects research projects. I want to give you a few headlines on what we have been doing and what you will hear about in more detail later.

HUMAN HEALTH EFFECTS

The most critical concern in the energy/environment area is human health effects caused by pollution. Scientists from the National Institute for Occupational Safety and Health, ERDA, EPA, and the National Institute of Environmental Health Sciences will be presenting papers for discussion in these areas:

- Development and use of biological screening systems
- New methods for evaluating hazards to population groups
- What we have learned about the interactions of energy-related pollutants with the mechanisms of biological systems.

TRANSPORT AND FATE

We will have a discussion of transport and fate: what happens to the pollutants after they are emitted, how they react and interact in the environment, and where they end up. Speakers from TVA, ERDA, the National Oceanic and Atmospheric Administration, EPA, and the Electric Power Research Institute will talk on:

- The Midwest Interstate Sulfur Transformation and Transport Study
- Emission transport from TVA power plants
- The Multi-State Atmospheric Power Plant Study
- Transport from Western Power Plants and Effects on Cloud Precipitation
- The Sulfur Regional Experiment.

MONITORING AND CONTROL

We will discuss the latest developments in monitoring and measuring environmental pollutants. The experts here include the National Bureau of Standards, the Coast Guard, NOAA, NASA, EPA, and ERDA. The topics include:

- New methods for measuring new pollutants from energy technology
- Latest remote monitoring instrument developments
- Special instrumental methods for measuring energy pollutants in western environments.

ECOLOGICAL EFFECTS

Finally we will focus on the ecological effects of energy development. The speakers are from the National Institute of Environmental Health Sciences, the Fish and Wildlife Service, NOAA, EPA, TVA, and ERDA. The subjects will cover virtually all areas of ecological impact, including:

- Effects on marine life of offshore oil and gas development
- Coastal, estuarine, and riverine ecosystem impact from coal, oil, and oil shale development, and effects from cooling systems
- Terrestrial ecosystem impacts of energy development and use, especially in the West.

By the end of this conference several things about the health and environmental effects research program should be clear. First, we are serious about doing the best we can to provide accurate information on threats posed by energy development. Second, and most important, is that we are not simply doing research by ourselves. We are vitally involved with seeing that our energy and environmental goals are compatible and that domestic energy resources are developed as rapidly as possible and are consistent with the protection of human health and the environment.

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DELBERT S. BARTH

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risk assessment methodology and epidemiological evidence

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OVERVIEW part IV

A Swedish Parliamentary Committee on Energy and Environment will report late this summer on a comprehensive, comparative evaluation of effects on health and environment from different energy sources, including nuclear and fossil fuel power plants. The National Swedish Institute for Radiation Protection will give background data on effects of ionizing radiation, and the National Swedish Environment Protection Board has reviewed effects from combustion products of fossil fuels, particularly oil and coke.

During the review, several key questions did arise which were felt to be of importance not only for Sweden but also more generally. The Committee on Energy and Environment therefore asked the Karolinski Institute to organize an international scientific symposium which was held in Stockholm March 8 through 11, 1977. About 30 experts from different countries, several from the United States, participated in the meeting. The World Health Organization, including the International Agency for Research on Cancer, was represented. The objective of the meeting was to consider current scientific knowledge about carcinogenic substances in air in relation to epidemiological data on lung cancer and available methods for assessing cancer risks from experimental data. The specific questions addressed to the participants of the symposium were the following.

- Can part of the increased incidence of lung cancer in urban communities be related to exposure to air pollutants? If so, is it possible to quantify dose response relationships after concern for smoking habits, occupational habits, and other habitual or socioeconomic factors?
- Can the approach used for radiation protection standards—that is, to extrapolate dose response relationships to low doses for which no epidemiological evidence exists—be applied to combustion pollutants? If so, for which pollutants and effects will such an approach appear justified?
- Do urban air pollutants contain substances that have proven carcinogenic or mutagenic in animal models, and can such data be used for risk evaluations in man?

The participants prepared working papers in advance of the meeting which formed the basis for the discussion. A report, Air Pollution and Cancer: Risk Assessment Methodology and Epidemiological Evidence, was prepared. This has been unanimously approved by the participants and will be published, together with the working papers, in the January 1978 issue of Environmental Health Perspectives.

RISK ASSESSMENT METHODOLOGY

If we first look at the risk assessment methodology, it can be said that for purposes of radiological protection, the International Commission on Radiological Protection (ICRP) considers that all doses are additive, no matter when or at what rate they are received. It was realized by them that this assumption was valid only if an arithmetic plot of response against dose yielded a straight line passing through the origin.

DOSE RESPONSE RELATION

This dose response relation was evident for the production of mutations and was adopted for late effects of radiation. The reasons for its adoption by ICRP were its practicality in managing radiological protection measures and the realization that in most cases this was conservative; that is, it was likely to overestimate the effects of low doses, possibly by a factor of two to four in the case of tumor induction.

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CARCINOGENIC CHEMICALS

As for chemical carcinogenesis, there has been a relatively small number of experimental studies of chemicals over a wide range of exposure doses. It is noteworthy, however, that for certain polycyclic organic compounds the relation between doses and responses resembles that for radiation. Such evidence supports the idea that for carcinogenic chemicals there is, for small doses from zero, a linear relation between dose and response. Also, certain epidemiological data for human exposures support such a hypothesis. This would also be in agreement with the mutation hypothesis for chemically induced cancer. A number of factors can influence the likelihood of a carcinogenic response to given chemical exposures. They include factors which control transport and metabolic activation or inactivation of carcinogens in the organism, effects of noncarcinogenic agents such as coal carcinogens, promoting agents, and inhibitors.

For penetrating ionizing radiation it is relatively easy to protect the target dose, meaning the concentration of ultimate carcinogens at the site of action in the tissues or sets. Due to the factors just mentioned, the estimation of the target dose of chemical carcinogens for a given tissue in relation to exposure becomes more complex. The situation was, however, considered comparable with that for ionizing radiation in the case of carcinogens which act on directly exposed tissues, for example, skin or bronchial epithelium.

CONCLUSION REACHED ABOUT DOSE RESPONSE

Taking all available data into consideration, including interaction of carcinogens and modifying factors and individual variability, the symposium reached the conclusion that in considering protection of human population and in the absence of firm evidence to the contrary, it is not justified to assume that there is a dose below which no response is obtained. Furthermore, it was said in the absence of relevant dose response data, the most appropriate way to estimate the risk of lung cancer is to assume that it will be directly proportional to the increase in dose. For small added doses, a simple linear dose response curve as used in radiation carcinogenesis is appropriate.

LINEAR ASSOCIATION OF AIR POLLUTANTS & LUNG CANCER

If it is assumed that there is a linear association between increase in exposure to air pollutants and increase in risk for lung cancer, this is in principle equal with the assumptions used in connection with radiation protection. For carcinogenic air pollutants which are not degraded in the ambient air and are transported over long distances, it will then also be meaningful to use the term collective exposure to evaluate quantitatively the risk for an increased incidence of, for example, lung cancer in a large population. The total number of cancers per year caused by a defined substance would then be the same if one thousand persons are exposed to a certain concentration as if one million persons are exposed to a concentration 1,000 times lower.

In connection with risk assessment methodology, the symposium also discussed in detail possibilities of extrapolation from experimental systems to man. I will not go into any details here, but just mention conclusions reached. It was thus stated that if a substance has been shown to be carcinogenic in an adequate animal test system, it should normally be dealt with as if it had been shown to be carcinogenic in man, unless adequate epidemiological evidence existed to the contrary.

Knowledge of the existence of possible interactions of different components of air pollution which may result in marked synergistic effects implies that great caution should be exerted in interpreting observations based on the effects of single factors of partial mixtures such as condensates. Positive results with a substance in a combination of appropriate short term bioassays should be taken as suggestive of possible carcinogenicity.

LUNG CANCER & AIR POLLUTION EPIDEMIOLOGICAL EVIDENCE

I will now turn to the discussions and conclusions on epidemiological evidence for a causal association between lung cancer and air pollution. The starting point for the discussion was that chemical agents derived from the use of fossil fuels and known to be carcinogenic or co-carcinogenic are present at higher levels in urban than in rural atmospheres. Furthermore, it was obvious that lung cancer is in general more common in urban than in rural areas. The single observation that the disease tends to be more common in urban areas is not by itself sufficient evidence that the disease is attributable to atmospheric pollution. It might be due to other features associated with urban living, such as smoking, drinking, and eating habits, the higher risk of infection or specific industrial hazards associated with employment.

CIGARETTE SMOKING

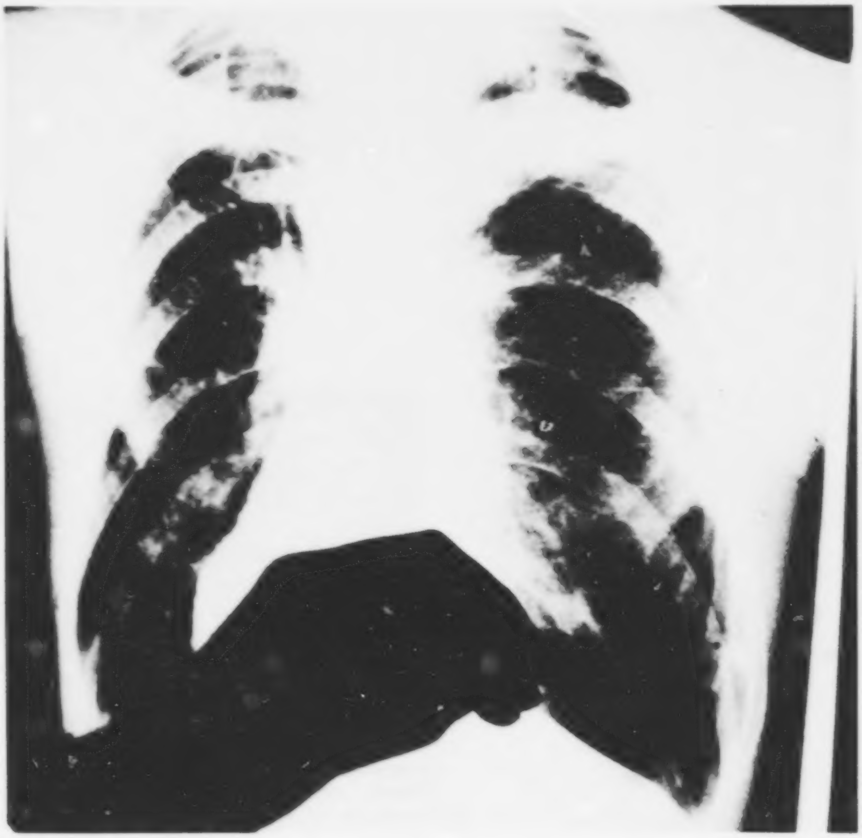
The importance of such factors which may confound the possible effects of ambient air pollution was discussed in detail. It was concluded that cigarette smoking is the predominant cause of lung cancer and an important component of urban-rural differences. Specific occupation and other aspects of urban life such as nutrition and alcohol consumption were not, in general, considered to be important as causes of the urban-rural differences in terms of absolute numbers, except perhaps in some special locations.

UPPER LIMIT OF ATMOSPHERIC POLLUTION

Because of air pollution, the incidence of lung cancer in different urban areas, in different states of the United States, and in different parts of several other countries varied with the degree of urbanization and also in relation to recorded measurements of the concentration of benzo-A-pyrene in the ambient air. This led some investigators to conclude that the lung cancer death rate in man increases by approximately 5 percent for each increment of pollution as indicated by 1 nanogram of benzo-A-pyrene per cubic meter. The symposium reached the conclusion that this estimate should be regarded as an upper limit of the possible effects of atmospheric pollution. There were several reasons, however, for questioning the quantitative value of such an estimate. Nevertheless, the data for men working in industries where they were exposed to the combustion products of coal confirm that these products could cause cancer of the lung. Taking into consideration all available evidence, including epidemiological data, experimental status, and the presence of carcinogenic substances in the ambient air, the most reasonable conclusion in light of present knowledge was that combustion products of fossil fuels in ambient air, probably acting together with cigarette smoke, have been responsible for cases of lung cancer in large urban areas, the numbers produced being in the order of 5 to 10 cases per 100,000 males per year. The actual rate will vary from place to place and from time to time, depending on local conditions over the previous few decades.

NEED FOR MORE RESEARCH

The symposium reached an agreement on several recommendations. They all reflected our ignorance and need for more research in this important field, particularly when compared with the much more exact knowledge in the field of ionizing radiation.



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As for the composition of urban air pollution, it was stressed that further monitoring of potential carcinogens should be made and that there is a need to have better indicators of the carcinogenicity of air pollutants than are now available.

As for risk assessment methodology, it was stressed that studies using a variety of bioassays should be undertaken to define the carcinogenic activity of individual air pollutants, with particular attention being paid to the relationship between target dose and exposure dose.

Experimental status on exposure to natural and synthetic mixtures of air pollutants should be undertaken in order to develop test procedures which can be used to assess the total carcinogenic potential of atmospheric pollution. Further and more detailed epidemiological studies were considered needed to take into account both host characteristics and environmental factors. In addition to the outdoor air quality and smoking history such factors as occupational exposure and indoor air pollution from cooking, heating, aerosol sprays and other people's smoking are of paramount importance.

The urban-rural differences for lung cancer are not consistent under all circumstances, and situations where they are most typical should be studied to provide clues to the further understanding of the etiology of the disease. The symposium also noted that there was an urban-rural difference for other forms of cancer. Not enough data came up with an evaluation of the reason for this urban-rural difference. It was pointed out, however, that studies should also be carried out in order to elucidate the reason for urban-rural differences in other forms of cancer than lung cancer.

DR. LARS FRIBERG

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keynote address

The Honorable Douglas M. Costle
Administrator
U.S. Environmental Protection Agency

OVERVIEW part V

FEDERAL-AGENCY COOPERATION

I very much appreciate this opportunity to be with you today, and I am delighted that you are here to learn more about our Interagency Program. I am especially pleased to note that some 17 different Federal agencies and departments are participating. Such cooperation is impressive. Rarely have we seen such coordination among so many Federal agencies, and even more rarely has such cooperation been accomplished with so little paperwork and so few Federal workers.

We can take pride in the accomplishments of this program in addressing the crucial task of assuring an adequate energy supply with proper environmental protection. When the Interagency Program was initiated in 1974, there were those who gave the program little chance for survival, let alone success. Putting $100 million a year into an interagency program was, in these critics' view, a somewhat doubtful exercise. The doubters have been proven wrong.

Time does not allow my giving credit individually to each of those involved in making this program a success. But I am proud of the work we have done in cooperation with TVA to develop alternative flue gas desulfurization technologies and to find better ways of using scrubber sludge. I am proud of the work we have done with the Department of Interior and the Bureau of Mines to further research coal cleaning technologies. I am proud of the work we have done with the U.S. Geological Survey and the National Bureau of Standards to assure consistent and accurate environmental data. And I am proud of the progress we are making with the Energy Research and Development Administration in monitoring the pollutants from new coal conversion technologies.

This work, and the work of other agencies involved in the Interagency Program, makes feasible the Federal effort to increase coal use. The health and environmental information and control technologies developed by the Interagency Program are those most urgently needed to respond to the critical energy needs we face today.

EFFECTS OF SULFUR COMPOUND EXPOSURE

And those needs are urgent. For example, the combustion of coal to supply energy in this country today releases approximately 22 million tons of sulfur compounds into the atmosphere each year. These sulfur compounds are harmful to health, disrupt agricultural productivity, and cause untold property damage. If we were to increase our use of domestic coal by two-thirds in the next 8 years without the control technologies developed under the Interagency Program, we would be spewing approximately 500 pounds of sulfur compounds per year into the atmosphere for every American alive. That is more than a pound per day per person. The natural dispersing capacity of the air is just not able to protect us from that type of abuse.

Fortunately, we will never have to discover what effect such a massive exposure to sulfur compounds and other coal-related pollutants will have on our health and our environment, because the Carter Administration is committed to using the best available means to assure the environmental compatibility of new coal-burning facilities and because the technologies and information produced by the Interagency Program are helping to provide those means.

While we have made much progress and have produced useful information on the entire range of energy/environmental issues, we cannot overlook the fact that many issues remain highly controversial. Scientists are not in full agreement on the fine points of a number of issues. But when the experts disagree and our best available information is not definitive, we must proceed on the basis of assuring the protection of the health and well-being of all our people. This is clearly the wisest course.

I am reminded of the story of the Roman bridge builders. The Romans built bridges of great durability though they had very little understanding of the stresses involved in such engineering design. The explanation is quite simple: The bridge designer was expected to stand beneath his own bridge while the Roman legions marched across above. In protecting the health and well-being of the American people, we must remember that we all have to stand beneath that bridge together.

We can pour only so much of our wastes into the air and water before human health and lives will be endangered. It is our job to ensure that we stay well under the limit. New technology must be designed with the full knowledge that air and water are finite and fragile resources. This is not to say that we should never use the air or water to receive appropriate levels of emissions. But when we do use our air and water resources in that manner, we must do so in a way that does not unnecessarily jeopardize public health and the environment. That is why, for example, we are committed to maintaining momentum in cleaning up pollution from automobiles.

CLEAN AIR – A PUBLIC HEALTH NECESSITY

There can be no doubt that clean air is essential to the health and welfare of all Americans. Scientific studies show a direct relationship between exposure to polluted air and the incidence of heart disease, nervous system disorders, lung cancer, emphysema, asthma, and other respiratory diseases, especially among infants and the elderly. Air pollution is also costly in terms of property, materials, and vegetation. We have made significant progress in cleaning up the air. Recent studies indicate that emissions of several pollutants from power plants, factories, and automobiles have begun to decline. The quality of our air has made a small but important reversal toward healthfulness. Many millions of Americans, expecially in large metropolitan areas, are beginning to see and feel the difference. There is still, however, much to be done before we can say we have fully achieved our clean air goals.

Clean air is not an aesthetic luxury; it is a public health necessity. Many regions of the country have not yet met the health-based primary ambient air quality standards. That is why the President and I have recommended tough but fair clean air standards for automotive emissions. Opponents believe these standards are too stringent and support alternative schemes allowing cars to remain up to five times as polluting. But, if the auto companies are not required to clean up, more severe restrictions must be placed on stationary sources if there is to be any hope of reaching our air quality standards. As far as I am concerned, this makes very little sense.

In many areas where such pollutants exceed the Federal ambient air quality standards, the automobile is by far the greatest single source of pollution, and some 96 million Americans now live in areas where concentrations of photochemical oxidants exceed Federal standards. We don't want to badger any single industry. But it makes far more sense to require four companies, headquartered in one city, to clean up their act, than to take off after thousands of separate stationary sources scattered across the land. That is why the Administration supports tough auto exhaust standards.

AUTOMOBILE— GREATEST SINGLE SOURCE OF POLLUTION

Critics charge that the added cost of the tougher standards included in the price of the automobile will place a serious burden on the consumer. To my mind, that is a phony argument. The added cost of the tough Administration proposal, over and above the cost of the auto industry-backed proposal, comes to only $70 by 1980. Even if health considerations required us to exercise a tougher optional standard by 1980, the total added cost would be only about $150.

I don't know how many of you have recently run your finger down the price list of options stuck to the window of a new car, but compared to chrome strips, vinyl tops, tinted glass, special wheel covers, radial tires,—not to mention air-conditioner, CB radios, and electric door locks—$70, even $150, is a real bargain. And remember, we are all under that bridge together. The little added investment in making our standards tough will be more than made up in added protection for all of us.

Finally, there are some remaining myths about the relationship between auto emission standards and fuel economy. Somehow the belief seems to persist that higher standards mean lower fuel economy. In the face of the growing scarcity of energy, this could be a sobering fact—if it were true. But here are the facts: Long before emissions controls and standards were imposed, fuel economy was on a steady decline. That decline continued briefly when the earliest and less sophisticated control technology was introduced. However, in 1975, when standards were significantly strengthened and cars sported more advanced smog control devices, fuel economy improved 13.5 percent over the year before. In 1976, there was an additional 10 percent improvement. Another 3.3 percent improvement was registered this year—bringing the total fuel economy improvement to 26.8 percent over 1974 cars. We expect the trend to continue, serving the interests of both environmental protection and energy conservation at the same time.

As President Carter noted in his energy message, "Our energy problems have the same cause as our environmental problems—wasteful use of resources. Conservation helps us solve both at once." And, clearly, our proposed tough emission standards do both.

ENERGY AND ENVIRONMENTAL ISSUES RELATED

In conclusion, I want to add a word about the President's energy program, which deserves our strong support. The program clearly gives to conservation the priority which environmentalists have long desired. To the extent that we reduce our demand for energy, we reduce the burden that energy production places on the environment. But, to me, the most important element of the energy program is that it was planned with environmental concerns central to its consideration from start to finish. Energy issues do not exist in a vacuum. Neither do environmental issues. Environmental requirements were carefully examined and related to our economic and energy goals throughout the development of the energy program.

The President is fully committed to the principle that our nation must have a strong environmental program as a necessary prerequisite to future progress in solving our energy and economic problems. Those of you here today, involved in the solution to our environmental and energy problems, are playing a vital role in the future health and well-being of all Americans. We face a great challenge. Together we can help our nation move forward toward a healthy, pollution-free environment for all Americans, while at the same time assuring sufficient energy sources to keep our nation strong and vital.

DOUGLAS M. COSTLE

A.B., Harvard University; J.D. University of Chicago Law School. Attended Woodrow Wilson International Center for Scholars; involved in independent research and writing on environmental programs and government organization, including meeting with cabinet ministers, journalists, and private groups in Western Europe. Diversified background—trial attorney, U.S. Department of Justice, investigating civil and criminal cases of federal civil rights in Mississippi; Attorney and Deputy Director of U.S. Department of Commerce on project designed to reduce unemployment in Oakland, CA.; headed study for recommendation on creation of EPA; helped prepare implementation plans and set up agency while on President's Advisory Council on Executive Organization; was Deputy Commissioner and Commissioner for Connecticut's Department of Environmental Protection; was Assistant Director for Natural Resources and Commerce, Congressional Budget Office; and member of Transition Team on Government Organization for President Carter. Member of the Bar in California and District of Columbia. Currently, Administrator, Environmental Protection Agency, Washington, DC.

questions & answers

The Honorable Douglas M. Costle
Administrator, EPA

QUESTION: You previously indicated that a large number of American citizens are in areas that presently exceed the national ambient air quality standard for oxidants. Would the Carter administration veto a new Clean Air Act if it contained the automobile industry-backed new car standard, as opposed to the one which will accelerate achieving the standard?

RESPONSE: The Honorable Douglas M. Costle (EPA)

It is really too early to answer what standards, if passed by Congress, the President would veto.

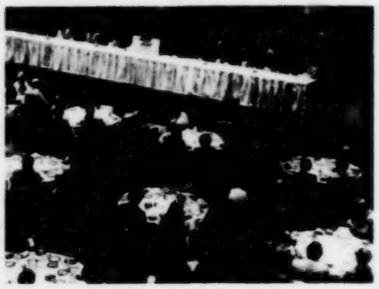
We were very disappointed in the House action, and I have said so publicly. I believe the President will speak on this issue as well. I think we will get a stronger bill on auto emissions from the Senate. So I believe it is premature to talk about a veto. It is, however, not too early to indicate that we were quite concerned about the bill as it came out of the House.

QUESTION: If the mandate is conversion from oil and gas to coal, I understand that a plant would have 2 or 3 years to put on the best available control technology. Can you comment on that and on EPA's possible move to change so that, with conversion, Best Available Control Technology (BACT) would be utilized at that time?

RESPONSE: Mr. Costle

It is hard to give a definite answer because the situation is floating. That specific question is addressed in the Clean Air Act Amendments that are now before the Congress. Depending on where we convert, it would be desirable to have the controls on before the switch is turned. In any event, there should be a certain date and a definite, enforceable schedule that gives us an element of predictability about when those controls are on. I feel this will be debated in the Senate, and I am not sure of the outcome when the legislation is finalized before both houses.

The President has acknowledged that there may be areas in the country where for public health reasons we will not be able to burn coal, even with the best of controls. There will not be very many of these places, but there are a number of assumptions necessary for this prophecy to come true. We must enforce vigorously against existing sources to get maximum controls. We must pursue policies that will allow us to turn over an old plant in favor of a new, better-controlled plant and equipment. Finally, we must ensure that, as we get into individual site situations in terms of cost, technology, and environmental impact, we come down to a bottom line that can be defended as a common sense solution in that particular site specific situation. It is very hard to generalize beyond that because we then get into aggregate statistics and they are too general. I am personally familiar with too many situations that are site specific, so it is very hard to use generalized figures without adding that very important caveat.



Without question, in some areas of the country where we now burn a lot of coal, much can be done to clean up existing sources. The plain fact is that in heavily industrialized parts of our country, air is no longer a free good but a commodity that is increasingly having a very positive economic value. To put it very simply, in any column of air in the country, there is only so much that you can put into it, so much capacity for that column of air to absorb waste before it gets unhealthy. In addition to getting it down to the point where it is healthy to breathe, we must continue to manage what is in that air in order to give ourselves the margin for growth for new industries, and that means that we are in the business of managing what goes into the air. That is an entirely new issue for state and local government to deal with, and it is no wonder that it goes down hard. It is a very sophisticated issue, and is a technologically and scientifically complex one.

We are also past the point where we can allow any single industry to preempt that management decision. Frankly, that is what the automobile industry is now doing, and I think that is the effect of the House bill.

QUESTION:

Why not develop an automobile that pollutes the same no matter what the climatic factor? One of the problems is that at low temperatures it emits three to five times as much CO.

RESPONSE: Mr. Costle

One of the areas of real disagreement between ourselves and the auto companies is what should the standards ultimately be for carbon monoxide. We recommended the statutory standard, and they recommended a somewhat more relaxed standard.

There are several reasons for our endorsement of that tougher standard. One is that we think we are probably underestimating the size of the problem. In many instances our monitoring networks have not been placed at ground level where the concentrations occur. There has also been an assumption in the past that there is a dose response relationship on CO. In fact, in most of the calculations that I have seen, there is assumed to be a dose response relationship that may not establish a threshold at which a person is directly affected. We have only monitored in a few areas, and we make the assumption under existing health projections, for example, that small towns do not have the problem, and I do not think that is a valid presumption. Moreover, the projections do not take into account the unhappy incidence of the person who both smokes and travels in heavy traffic congestion. There seems to be very little doubt that he is getting an exposure that is far more serious that we have provided in previous calculations.

QUESTION:

Sir, are there circumstances under which you would support legislation to pay plants to retrofit their cleanup devices on existing stationary sources?

RESPONSE: Mr. Costle

In effect the Clean Air Act does that now. When you have to go back on existing sources and roll back the emissions in order to meet a prescribed ambient level, that is effectively what you are doing. In older urban areas of the country where there is dense concentrations of industry, as technology is available and you can retrofit at an acceptable economic cost, that will be one of the ways you go about the job of managing the air resource that you have always left for yourself as a margin for continued growth and new industry. So the answer is yes, the policy does encourage retrofit on older plants.

QUESTION

What is our policy on increasing concentrations of carbon dioxide and the possible greenhouse effect?

RESPONSE: Mr. Costle

I am not a scientist and I have not reviewed that evidence or data. I have read what I suspect most of you have read in the newspapers only; so I do not know what our policy will be. That is one of the questions that obviously we need to be looking at, but I have not had an opportunity to get into it. In fact, I have spent probably 50 percent of my time in the first 3 months doing something different than I expected: I have been testifying before the Congress. At the last session of Congress, EPA testified 137 times before 55 different committees and subcommittees, and not one of them did not appear to have a very legitimate interest in something that we were doing.

Now, when that record was set, and it was a record for EPA, at this point in time in the last session we had appeared 26 times. So far at this session of Congress we have appeared 55 times. There are, therefore, questions that I have not had a chance to get into yet.

CHAPTER 2

fuel processing

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FUEL PROCESSING

Marvin I. Singer
Director,
Division of Environmental and Socioeconomic Programs
Energy Research and Development Administration

INTRODUCTION

I am pleased to address this second National Conference on the Interagency Energy/Environment Research and Development Program. It is especially fitting for me to be here since ERDA's and EPA's programs—both in their objectives and, often, in their execution—are closely intertwined.

The papers this morning all deal with the environmental effects of emerging technologies for energy production. Mr. Bruce Henschel of EPA's Industrial Environmental Research Laboratory at Research Triangle Park, North Carolina, assesses the environmental impacts from a unique combustion method—fluidized-bed combustion. Messrs. Eugene Harris and Thomas Powers of EPA's Industrial Environmental Research Laboratory at Cincinnati, Ohio, discuss pollution control programs for a new fuel source, oil shale. Mr. William Rhodes, also from EPA's Research Triangle Park Laboratory, discusses environmental considerations of gaseous and liquid synthetic fuels. And Messrs. Robert Olexsey and George Huffman, from EPA's Cincinnati Laboratory, examine pollution abatement for wastes as fuel or, as ERDA was calling it last year, biomass. One of the interesting things about all of these processes for energy production is that each can be considered a form of pollution control, as contrasted with the production of energy from a conventional coal- or oil-fired power plant. I will present some comparisons along these lines as a concluding thought.

As the rapporteur for this session on fuel processing, I should like to summarize briefly the main points from each of the four papers and to emphasize the areas of commonality in the presentations. Following my summary of the four papers, each author will have the opportunity to add briefly any important or clarifying points that I may have overlooked. Following the authors' brief comments, we will open the discussion to questions from the floor. To give some additional perspective to the topics of the four papers, I have prepared a few slides which represent some of the issues, concerns, and coordinating activities between ERDA and EPA involving the technologies we will be discussing. While this additional material may not be discussed directly in the papers, it provides some interesting background orchestration to the discussion.

The Federal Interagency Energy/Environment Research and Development Program was inaugurated 2 years ago to assure that energy development, both from existing supplies and from new energy sources, is accompanied by effective environmental controls. ERDA is pleased to cooperate with EPA and other Federal agencies in achieving this goal. Indeed, ERDA's enabling legislation, the Energy Reorganization Act of 1974, and the Federal Nonnuclear Research and Development Act of 1974, both mandate that environmental considerations be basic to ERDA's decisions on technology research, development and demonstration. Since such technology development can lead to new environmental problems, the pooling of expertise and resources from several different Federal agencies will allow these problems to be addressed in the most efficient and timely manner.

One of the common themes repeated in each of the four papers is a three-sided approach to environmental problem solving. I would like to summarize this common approach briefly before discussing the individual papers. First, the gaseous, liquid and solid wastes emitted by the different processes are characterized, both quantitatively and qualitatively; second, the ecological and health and safety impacts of these pollutants are determined; and third, the design and development of alternative methods of pollution control are assessed (Figure 1).

energy
environment II

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Figure 1.

Strategy for environmental research and development

- CHARACTERIZATION STUDIES
- EFFECTS STUDIES
- CONTROL TECHNOLOGY DEVELOPMENT

The first element of this strategy—characterization—necessarily includes baseline monitoring of ambient data and the study of process flow streams. This permits emissions from different points in the energy processes to be measured against background pollutant levels. Once emission sources and levels have been pinpointed, their effects on the surrounding environment can be determined. Finally, after the types, amounts, sources, and effects of pollutants from energy process streams have been determined, methods of pollution control can be developed.

Figure 2.

Pollution abatement methods

- PRETREATMENT OF INPUT STREAMS OR "PRE-COMBUSTION CLEANUP"
- MODIFICATION OF TECHNOLOGY OR "CHANGE IN PROCESS VARIABLES" OR "CHANGE IN COMBUSTION METHOD"
- MECHANICAL OR CHEMICAL CONTROL DEVICES OR "POST COMBUSTION CLEANUP"

POLLUTION CONTROL APPROACHES

The environmental problems caused by the production of fuels and energy can be attacked at different points in the fuel production/combustion chain (Figure 2).

- Precombustion cleanup includes such techniques as coal beneficiation, or the use of solvent-refined coal as a fuel.
- Postcombustion cleanup includes such techniques as flue gas desulfurization, electrostatic precipitators, and cyclones.
- Cleanup by using innovative fuel combustion techniques includes fluidized-bed combustion.

All of these are approaches to pollution control.

A fourth approach, the modification of process variables, can also lower the levels of emitted pollutants. For example, in the Synthane process for high Btu gasification, adjusting fuel injection parameters, reaction temperatures, and product gas residence times can significantly reduce tar, oil, and phenol levels in process waste waters.

A particular energy technology may use different combinations of these various methods of controlling pollution, depending on the economics involved and the degree of control required. The papers presented describe how environmental research strategies and the different options for pollution control have been applied to four specific energy technologies. I would now like to summarize the four papers.

ENVIRONMENTAL ASSESSMENT–FLUIDIZED-BED COMBUSTION

Mr. Henschel finds that fluidized-bed combustion (FBC) of coal appears to be environmentally favorable for heat, steam, and power generation. The current ERDA program includes a number of projects: a 30 MW boiler at Rivesville, West Virginia; cofunding of several planned industrial/commercial/institutional units, one of the first of which is expected to be a 100,000 lb/hr boiler (equivalent to about 10 MW) in the Georgetown University physical plant; a 13 MWe combined cycle system using a pressurized fluid bed to be built in Wood Ridge, New Jersey; and a Component Test and Integration Unit (CTIU) at Morgantown, West Virginia, to test various elements of atmospheric fluidized-bed combustion systems. The EPA efforts being coordinated with ERDA's program will determine the environmental impacts of the fluidized-bed technology and develop environmental control technology to reduce these impacts.

One of the first priorities of the EPA program is to identify emission levels of all potential pollutants from fluidized-bed combustors and, where standards or guidelines do not already exist, to try to define the degree of control required. Consequently, studies have been conducted to project possible emissions of SO_2, NO_x and other compounds, based upon theoretical calculations and engineering considerations. The results to date suggest no specific environmental problems, but additional emissions data are required to enable firm conclusions.

RESEARCH BOUNDARIES

Another key activity is an attempt to establish research boundaries by deriving a list of the compounds to be considered. A list of 1,093 substances has been derived by considering:

- Elements and compounds known to be present in coal and limestone/dolomite
- Substances known to be emitted from coal combustion/conversion processes
- Substances with a potential for formation during combustion and for which Threshold Limit Value (TLV) and lethal dose (LD) data are available.

A separate list of 650 substances has been compiled using the following criteria:

- Substances known or suspected to be emissions from coal or oil processing
- All classes of substances represented
- Substances for which TLV or LD data are available, or for which environmental standards/guidelines/criteria are proposed or promulgated, or which are on certain other EPA listings.

An attempt is currently underway to integrate the two lists.

In order to determine emissions of up to 1,093 substances on a cost-effective basis, a staged sampling/analysis approach has been proposed, consisting of three levels. Level 1 involves comprehensive screening using analytical techniques which sacrifice accuracy and compound specificity in order to identify possible problem areas in a cost-effective manner. Level 2 uses more accurate, compound-specific techniques to explore identified problem areas. Level 3 includes routine monitoring of those pollutants identified as specific problems in Level 2. The Level 1/2/3 approach is being refined as further experience is obtained.

A comprehensive source sampling program is being undertaken in order to develop the emissions data base necessary to set environmental standards/guidelines and to provide the emissions information necessary for comparison with environmental objectives. In some cases, an ambient monitoring program may be warranted as well.

Mr. Henschel presents some analytical results that are available from the samples already taken. In summary, he finds that fluidized-bed combustion may be expected to control emissions of SO_2 and NO_x below the levels now required by the EPA New Source Performance Standards for large conventional coal-fired boilers. Particulate control adequate to meet the EPA emission standard for conventional coal boilers has not been demonstrated, either for atmospheric or pressurized fluidized-bed combustion. In the case of atmospheric systems, particulate control will probably be similar to that for a conventional boiler burning low-sulfur coal. Control at high temperature/pressure to meet conventional boiler emission standards for a pressurized fluidized-bed combustor will require control technology which has not yet been demonstrated. Data on emissions and control of potential pollutants other than SO_2 and NO_x, including those in liquid and solid streams, are not adequate to allow firm conclusions regarding their emission levels (Figure 3).

Figure 3.
Direct combustion

CONCERN

- ALTHOUGH NO_X AND SO_X EMISSIONS ARE BELOW NEW SOURCE PERFORMANCE STANDARDS FLUID BED COMBUSTION MAY EMIT MORE SMALL PARTICULATES THAN CONVENTIONAL BOILERS, AND GENERATE A DIFFERENT TYPE OF WASTE MATERIAL.
- DEVELOPING PARTICULATE CONTROLS FOR HIGH TEMPERATURES/PRESSURES AND EFFECTIVE WASTE DISPOSAL METHODS IS IMPORTANT TO FBC USE.

COORDINATION

- EPA IS INVOLVED IN FBC EMISSIONS CHARACTERIZATION FOR ERDA PROJECTS AND HAS HELPED WITH COAL/OIL SLURRY TEST PLAN.

ERDA ACTIVITIES

- ENVIRONMENTAL ASSESSMENTS OF ALL COMBUSTION PROJECTS ARE EITHER COMPLETED OR UNDER WAY.
- EXTENSIVE FBC AND COAL/OIL SLURRY CHARACTERIZATION STUDIES HAVE STARTED.

MULTIMEDIA ENVIRONMENTAL GOALS

Independently of the characterization studies, EPA is developing Multimedia Environmental Goals (MEGs). Based on health and ecological considerations, these MEGs set targets for emission levels. Actual emission measurements from fluidized-bed combustion facilities will then be compared to the MEG targets. These multimedia environmental comparisons will assist in deciding what pollutants should receive emphasis in the EPA program and in planning the control technology development program for fluidized-bed combustion.

In parallel with the fluidized-bed combustion environmental assessment effort, EPA is conducting a significant program to develop suitable environmental control technology. EPA is approaching the problem via three of the methods described earlier:

- Modification of process operating design conditions
- Pretreatment of input streams
- Adding on control devices.

SO_2 REMOVAL

First, testing is underway on a 0.63 MW pressurized fluidized-bed combustor to determine SO_2 removal in the pressurized bed as a function of sorbent feed rate. Results show that the dolomite used in this study is more effective than limestone on the basis of the sorbent feed rate, expressed as the sorbent calcium-to-coal sulfur molar ratio; also, limestone becomes more effective in a pressurized system when the bed temperature is high enough to result in calcination of the calcium carbonate.

Second, precalcination of the limestone feed to pressurized fluidized-bed combustors is being studied as a means for reducing sorbent requirements, thus reducing the quantity of solid residue. Results show that precalcination can make the limestone as effective as the dolomite on the basis of the calcium-to-sulfur molar ratio.

Third, among the particulate control devices to be tested in the near future are a high temperature/pressure granular-bed filter, an Aerodyne cyclone to be tested on a higher temperature/pressure control test stand, and conventional scrubbers, fabric filters, and electrostatic precipitators. Another add-on option being studied is sorbent regeneration, which should reduce fresh sorbent requirements and, hence, the quantity of solid residue. Since it is technically feasible to regenerate the sorbent by means of reductive decomposition, fresh sorbent requirements with regeneration may be reduced to only 15 to 20 percent of that which would be required to maintain the same degree of sulfur control without regeneration.

SYNTHETIC FUELS PROGRAM

Conversion of coal to synthetic fuels represents another option for controlling pollution from coal utilization (Figures 4 and 5). However, while some synthetic fuels are extremely clean-burning, their manufacture can create environmental problems. Consequently, EPA's present synthetic fuels program, as described by Mr. Rhodes, encompasses the broad scope of environmental assessment and control technology development.

For several years, EPA has been conducting characterization tests on coal and coal use. Feedstock analysis was emphasized early because it was considered essential for the evaluation of environmental impacts. With EPA funding, such agencies as the U.S. Bureau of Mines and the Illinois State Geological Survey produced very comprehensive descriptions of U.S. coals, particularly with respect to their sulfur content, washability characteristics, trace element makeup, and availability.

MINERAL MATTER IN COAL

Characterization of the mineral matter in coal continues to be funded under a current grant. A number of whole coals and wash residues have been analyzed to date. A complementary study for the characterization of coal and coal residue has produced analyses of both whole and demineralized coal samples. Investigation of the effects of pyrolysis on the distribution of trace elements and collection of data on the solubilities and toxicities of potential pollutants contained in solid coal waste have also begun.

EPA has sponsored a number of reports that project the types, quantities, and effects of potential pollutants associated with coal conversion. Results have included chemical, physical, and toxicity characterizations of various elements and compounds. Reports on potential emissions from coal and oil extraction processing, trace constituents from gasification processes, and continuing evaluations of multimedia environmental goals are examples of this type of work (Figure 4).

Figure 4.
Synthetic fuels

CONCERN

- INTERMEDIATE STREAMS AND PRODUCTS CONTAIN POTENTIALLY TOXIC/CARCINOGENIC ORGANIC COMPOUNDS.
- COMMERCIAL PROJECTS, DUE TO THEIR SIZE, ARE THE FOSSIL TECHNOLOGIES MOST LIKELY TO PRODUCE SIGNIFICANT SOCIOECONOMIC IMPACTS.
- IN-SITU GASIFICATION CAN DISRUPT AND CONTAMINATE GROUNDWATER AQUIFERS.
- SYNTHETIC FUELS PLANTS MAY GENERATE AIR, WATER, AND SOLID WASTE EFFLUENTS.

COORDINATION

- ERDA PARTICIPATES IN EPA'S SECTOR GROUP; EPA IN ERDA'S ENVIRONMENTAL ASSESSMENTS.
- ERDA IS COORDINATING WITH EPA ON MONITORING STUDIES FOR UPCOMING LOW-BTU PROJECTS.
- ERDA/EPA COOPERATIVELY ANALYZE IN-SITU GASIFICATION LIQUID EFFLUENTS.
- ERDA HAS REVIEWED THE EPA PROPOSED LURGI HIGH-BTU GASIFICATION PLANT'S NSPS.

ERDA ACTIVITIES

- ENVIRONMENTAL REVIEWS ARE AMONG CRITERIA FOR CONTRACTOR SELECTION FOR INDUSTRIAL GASIFIER PROJECTS.
- SIGNIFICANT EMISSION CHARACTERIZATION/ANALYSIS AND OCCUPATIONAL EXPOSURE STUDIES ARE UNDER WAY AT PILOT PLANTS.
- ERDA DOES GROUNDWATER MONITORING AT IN-SITU RESEARCH SITES.

Attempts have also been made to characterize the scope and complexity of the synthetic fuels industry itself. For instance, a series of reports on 11 gasification and liquefaction processes have discussed the potential pollutant problems associated with each primary module and effluent stream, and a summary report has compared all conclusions. Additional familiarity with environmental problems of synthetic fuel plants was gained through a series of field trips to overseas industrial sites.

PROCESS-SPECIFIC LEVEL

EPA is also studying the environmental impacts of synfuel production on a process-specific level. For example, a series of environmental assessments of low Btu gasification will be made during 1977 at four sites, both Federal and private. At one of the sites, operations will be coordinated with an ERDA-funded program. General and specific test manuals are being prepared. To assess analytical techniques, grab-samples of ash, particulates, gases, liquids, and tar from several U.S. plants have been analyzed in the laboratory. In addition, a technical information system for project support has been established with over 9,500 citations.

The coal liquefaction environmental assessment program includes preparation of an overview document; pilot plant site visits, including one to ERDA's Solvent Refined Coal Pilot Plant at Fort Lewis, Washington; and combustion testing of both coal and solvent-refined coal.

POLLUTANT CONTROL FROM SYNTHETIC FUEL

Several approaches to control pollutants from synthetic fuel processes are being tried. Synthetic fuels research within EPA is being closely coordinated with related programs in both physical and chemical coal cleaning. ERDA's Division of Coal Conversion and Utilization has just sponsored a study by Carnegie-Mellon University* which indicates that levels of tars, oils, and phenols in the waste water from certain high Btu combustion processes can be lowered substantially by adjusting process parameters. Additional control devices applicable to synthetic fuel processes are also being researched. EPA recently awarded a contract for converter output control technology development. Projected results will include a study of the deactivation effect of trace compounds in coal-derived gases in a shift converter, and participation in the establishment of an acid gas removal facility for pollutant studies under grant funding. A recent award has also been made for pretreatment and waste control technology development.

Three major institutional research grants have been awarded recently. Under the first award, research will include screening of a large number of chemical species, determination of the effects of coal conversion reaction parameters on production of these species, and cataloging of kinetic data pertinent to the rates of formation of the significant pollutants. The second grant is for testing and evaluating a gas cleaning facility for gases from a bench reactor. A 5-year program has been initiated under the third grant:

- To assess biological and chemical treatment for waste waters from fuel conversion
- To determine environmental impact and health effects of treated waters
- To conduct bench-scale studies for developing water treatment design criteria.

Studies are also being initiated on selected "model" organic compounds and will then move to tests of composite waste streams.

R&D FOR CONTROL OF POLLUTION FROM OIL SHALE

Messrs. Harris and Powers describe the application of the three-fold approach to environmental R&D as applied to oil shale. Extraction process gaseous emissions, wastewater effluents, and spent shale wastes will be identified and characterized. EPA is studying the fate in fresh waters, ground waters, and air of specific pollutants resulting from oil shale development. Studies are also underway to monitor surface and ground water quality near oil shale facilities and to characterize emissions from the gasoline derived from shale oil (Figure 5).

Figure 5.
Oil shale

CONCERN

- SIGNIFICANT LAND AREAS WILL BE DISRUPTED DURING MINING AND WILL BE REQUIRED TO DISPOSE OF SPENT SHALE.
- BOTH WATER USE AND CONTAMINATION MAY AFFECT DEVELOPMENT AND USE OF OIL SHALE DEPOSITS.
- IN-SITU RETORTING CAN DISRUPT AND CONTAMINATE GROUNDWATER AQUIFERS.

COORDINATION

- ERDA IS PART OF THE INTERIOR OIL SHALE ENVIRONMENTAL ADVISORY PANEL AND EPA'S SECTOR GROUP.

ERDA ACTIVITIES

- COMPREHENSIVE ENVIRONMENTAL MONITORING IS PART OF ERDA'S IN-SITU OIL SHALE PROJECTS.
- ERDA IS DOING THE ENVIRONMENTAL DEVELOPMENT PLAN FOR THIS PROGRAM.

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*Environmental Assessment in the ERDA Coal Gasification Development Program, CMU, Pittsburgh, Pa. (March 1977)

OIL SHALE POLLUTANT EFFECTS STUDIED

The effects of pollutants from oil shale activities are also being studied extensively. Health effects of oil shale development are being investigated by ERDA, the U.S. Navy, the National Institute of Occupational Safety and Health (NIOSH), and EPA. The Research Triangle Park Health Effects Research Laboratory of EPA is assessing human exposure/effects relationships and evaluating hazards to man under controlled experimental conditions. The NIOSH studies address the occupational health of oil shale workers, and the Navy research concentrates on health effects associated with the burning of fuel oil derived from shale. The work being done by ERDA and EPA is in the general fields of toxicity and carcinogenicity.

By far the most widespread environmental research efforts are in the field of ecological effects. Agencies involved in this field include ERDA, the U.S. Department of Agriculture, the U.S. Bureau of Mines, the U.S. Geological Survey (USGS), the U.S. Navy, and EPA. Emphasis has been placed on revegetation and water and land use. The acute and chronic toxicological effects on freshwater organisms and ecosystems of pollutants released by oil shale processes will be determined.

Among the other agencies funding research in biological transport phenomena are ERDA and the U.S. Fish and Wildlife Service. ERDA areas of interest include repair of damaged cells, cell regulatory systems, molecular damage of DNA, and proteins. The Fish and Wildlife Service is investigating the impact of western energy development on water sources and subsequent effects on fish and wildlife.

Extraction and process control technology methods applicable to oil shale also are being researched. For example, test facilities are nearly completed to develop methods for spent shale disposal and revegetation. Other activities are oriented toward defining and/or developing timely, effective environmental control technology as needed for the industry's growth.

WASTES-AS-FUEL PROCESSES

Technology development in the wastes-as-fuel area has progressed to the point that several full-scale systems are operational, under construction, or planned. Messrs. Olexsey and Huffman state that as operational experience accumulates, the environmental aspects of waste-to-energy processes are becoming more clearly defined.

Thermal processes for recovering energy from solid wastes are of three generic types—mass burning, cofiring, and pyrolysis. Mass burners, or waterwall incinerators, produce steam through direct combustion of solid waste. Cofiring produces steam and/or electricity through combustion of processed solid waste and some fossil fuel, such as coal or fuel oil, in a fossil-fuel fired boiler. Pyrolysis plants utilize some degree of destructive distillation to convert waste material into gaseous, liquid, or solid fuel products. All three types display unique emissions characteristics which call for extensive environmental research.

Because of the relative infancy of U.S. waste-to-energy technology, operating experience is not extensive. Although a comprehensive EPA-sponsored program to characterize pollutants from waste-to-energy processes is just getting underway, some air emissions data are available from operating plants. For example, Messrs. Olexsey and Huffman report that cofiring refuse with high sulfur coal results in an increase of some pollutants but a sharp decrease in SO_2 emissions as the amount of refuse is increased. Chloride emissions, however, appear to increase about 30 percent when refuse is burned with coal. Particulate emissions also seem to increase when waste is cofired with coal. However, insufficient data have been gathered to lead to any firm conclusions.

energy
environment II

Operating experience at pyrolysis plants is far less extensive than it is at cofiring or waterwall incineration plants. Full-scale systems are often proprietary and are generally just now starting up operation. Furthermore, comparisons between pyrolysis plants must be approached with caution since pyrolysis processes vary in concept from pure pyrolysis with no air addition to starved-air combustion operations.

Wastewater effluents from mass burning plants can be in the form of ash quench water or, in some cases, scrubber water from particulate control devices. Liquid discharges from waste cofiring operations are limited to sluice waters from ash rejection and scrubber waters from particulate removal or flue gas desulfurization processes. Pyrolysis liquid effluents can result from several sources—gas scrubbing, water and oil separation, char and ash sluicing, and discharge of intermediate process liquids.

No large base of data on waterborn pollutants discharged from waste-to-energy plants yet exists. However, sampling of sluicewater effluents from one cofiring plant showed no significant differences between coal-only and cofiring operations in the yield of potentially hazardous pollutants such as cadmium, chromium, or mercury. However, total dissolved solids (TDS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were higher for sluicewater from the coal-plus-refuse-derived fuel operation.

R&D ON CONTROL DEVISES

Extensive research is being carried out to develop control technologies for the unique emissions characteristics demonstrated by wastes-as-fuel processes. Several types of air pollution control devices have been employed on waste combustion, cofiring, and pyrolysis processes. Air pollution control has, to this point, received particular attention at waste-to-fuel plants, with most attention to particulate control. There is very little operational experience relating to wastewater and residue pollution control.

Early-generation European waterwall incinerators employed mechanical collectors or low-energy impingement wet scrubbers. Later-generation waterwalls use high-energy venturi scrubbers and electrostatic precipitators to control particulate emissions. Most new plants use, or plan to use, the more efficient electrostatic precipitators. Furthermore, the need for more efficient particulate collection and also for effective gaseous emission control has resulted in experimental development of hybrid systems and completely new equipment such as "wet" electrostatic precipitators.

Early this year, EPA contracted for air pollution control research for waste-to-energy processes. The goal of this effort is to develop environmentally acceptable air pollution control processes that can be retrofitted onto existing plants or installed in new facilities. EPA also plans to award, in the near future, a similar contract to develop water pollution control technologies for waste-to-energy systems.

OBSERVATIONS ON EMERGING TECHNOLOGIES

As a concluding thought, I would like to return to something I said at the beginning of my talk—that some of these new technologies for energy production can be thought of as methods for effecting pollution control. Based on estimates from planning studies sponsored by ERDA and other agencies, such as the Council on Environmental Quality, we have made the following preliminary observations regarding the emerging technologies discussed here this morning:

- For producing electric power from high sulfur coal, fluidized-bed combustion or solvent refined coal reduce air pollution. Both technologies appear more desirable from the standpoint of air pollution than does the use of low sulfur coal with no scrubber. Both compare favorably with the air pollution control achieved using flue gas desulfurization and high sulfur coal.

- We talk about siting typical commercial size mine-mouth conversion facilities in the West. If we consider choices for coal utilization and how these choices impact local communities, then a 250 million standard cubic feet per day high Btu coal gasification plant would produce less air pollution and use less water than a 1,000 MW coal-fired power plant. However, solid wastes would be greater for the gasification plant.

- Siting a 50,000 barrel per day coal liquefaction plant at the mine mouth would produce, except for hydrocarbons, less air pollution than a 1000 MW coal-fired power plant. In all cases, however, the coal liquefaction plant would cause more air pollution than a 250 million standard cubic feet per day coal gasification plant. Water requirements for the liquefaction plant would be about double those for the gasification plant.
- And, finally, a 50,000 barrel per day oil shale plant would produce, except for sulfur oxides, less air pollution than the same size coal liquefaction plant. The shale plant would require about half as much water, but solid wastes would be about 27 times as great.

VALIDATION BY EXPERIMENTATION

Again, these are some directional indications we now have from planning efforts at ERDA. These directional indications must now be validated by experimental data.

MARVIN I. SINGER

B.S., Chemical Engineering, Massachusetts Institute of Technology; M.S., Chemical Engineering, Columbia University; M.S. Industrial Engineering, University of Pittsburgh. Experience in minimizing environmental and socioeconomic impacts of fossil energy actions, environmental assessment. Served as ERDA's Assistant Director for Environmental and Socioeconomic Impact, and staff member on President's Council on Environmental Quality. Prior to governmental service was on planning staff of large, private corporation analyzing mergers, design engineering, and economic evaluations of refinery and petrochemical processes. Currently, Director of Environmental and Socioeconomic Programs, ERDA, Washington, DC.

questions & answers

Mr. Francis R. Hull
Consulting Engineer

Mr. Ben H. Lim
EPA

QUESTION:

I suspect that the energy value obtained from solid waste is not worth the cost it would take to collect it and that we have failed to develop proper control methods which will make onsite incineration possible.

In the city of New York, for example, onsite incineration has virtually been eliminated in favor of compaction. The city is running out of landfill. The compacted sludge of refuse is largely being put in municipal incinerators. The compacted refuse requires much higher temperatures for combustion and also contains bottles and cans that have been mixed in the refuse. This material then melts on the refractory of the incinerator and causes further problems.

All of these problems associated with the collection and incineration of compacted refuse cost the city of New York about $300 million a year, which is also paid for by the federal government. This $300 million is the approximate cost of collecting and disposing refuse that apartment house incinerators dispose of at no cost whatever.

I would like your comments on the possibility that onsite incineration may be an approach that we should at least investigate.

RESPONSE: Mr. Robert A. Olexsey (EPA)

Robert A. Olexsey

The question was, should we not be looking more intensely at onsite, small scale disposal systems? As I understand it, we now are. We are spending more effort in that area than we did in the past, judging by the increase in our budget this year.

QUESTION:

On fluidized-bed combustion with calcium to sulfur ratios of 4 to 5, we are talking about large solid waste problems. What is your opinion on the feasibility of perhaps grinding and reusing the spent sorbent? I am not talking about regeneration now, but about exposing the unreacted area of the sorbent in order to decrease the calcium to sulfur ratios.

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RESPONSE: Mr. D. Bruce Henschel (EPA)

First, I hope that commercial systems will not frequently run calcium to sulfur ratios up to 4 to 5. When grinding and reusing it, that certainly is a possibility. However, it is not one that we have experimentally investigated, and it certainly is something we would be interested in studying further.

One application, incidentally, is to use this spent material for scrubbers. If one has a fluidized-bed boiler and a conventional boiler with an FGD onsite, the matter used in the fluidized bed might still have enough reactivity to be used in the scrubber.

QUESTION:

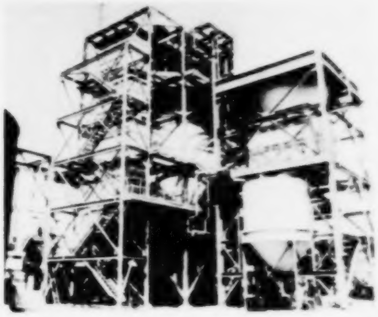
Are there any research programs studying the disposal alternatives for generated solid wastes from fluidized beds?

RESPONSE: Mr. Henschel

There are basically two questions. One involves disposal of the residue in an environmentally acceptable manner. The other involves utilizing this residue to not only minimize the environmental impact but also to give some market potential.

We have several studies under way for studying environmental impact of residue disposal, leaching properties, and so forth. One is with Westinghouse Research Laboratory, which at this point is basically a laboratory program, including some lysimeter work. The other study with Ralph Stone and Company involves lysimeter testing.

We are developing a program to study not just lysimeter testing but also field cell testing. The largest field cell we envision would be a 100 feet long by 100 feet wide by 5 feet deep, using residue from the 30 megawatt Reevesville fluidized-bed boiler. We also have solid residue characterization work being done for us by TVA.



QUESTION:

In using technology to obtain a marketable by-product, in this case elemental sulfur, are there any programs to study the markets for these by-products to the extent that they will not become solid waste problems?

RESPONSE: Mr. Henschel

EPA's program emphasizes the environmental impact of material disposal. Most of the work involving agricultural and nonagricultural uses is being sponsored by ERDA. A couple of the major ERDA programs in that area include the Department of Agriculture researching the uses of the material. There are a variety of smaller projects as well.

technical discussion

ENVIRONMENTAL ASSESSMENT OF THE FLUIDIZED-BED COMBUSTION PROCESS

D. Bruce Henschel
Office of Research and Development
Office of Energy, Minerals, and Industry
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina

INTRODUCTION

In parallel with efforts in the United States to develop new energy technologies, the U. S. Environmental Protection Agency (EPA) is conducting a contract research and development program aimed at environmental characterization of the developing technologies. The objective of the EPA program is to identify potential environmental problem areas, and to develop any necessary environmental control technology, while the energy technology is still under development, so that any necessary environmental controls can be integrated into the energy technology on the most timely and cost-effective basis.

One promising new energy technology that is being developed is fluidized-bed combustion of coal for heat, steam, and power generation. The U.S. Energy Research and Development Administration (ERDA) is conducting a substantial program to develop fluidized-bed coal combustion technology. The ERDA program currently includes a number of fairly large fluidized-bed combustion facilities, including: (1) a 30 MWe boiler at Rivesville, West Virginia (currently in the startup phase), to be operated with the bed at essentially atmospheric pressure; (2) co-funding of several planned atmospheric-pressure industrial/commercial/institutional units, one of the first of which is expected to be a 100,000 lb steam/hr (45,400 kg/hr) boiler in the Georgetown University physical plant; (3) a 13 MWe elevated pressure combined cycle system to be built in Wood-Ridge, New Jersey; (4) co-funding of a 30 MWe pressurized boiler to be installed in Great Britain under the auspices of the International Energy Agency; (5) a 6 MWe atmospheric-pressure component test and integration unit (CTIU); and (6) an analogous 3 MWe pressurized CTIU. The ERDA program also includes a number of support projects and design studies. Other organizations conducting efforts to develop fluidized-bed combustion are: the Tennessee Valley Authority (TVA), which is designing a full-scale fluidized combustion utility plant; and the Electric Power Research Institute (EPRI), representing the electric utility industry. One component of the EPRI program is a 3 MWe atmospheric-pressure unit being built in Alliance, Ohio.

The EPA program, being conducted in coordination with the development effort described above, is funded at $4.0 million in fiscal year 1977. This program has been discussed previously (References 1 and 2). The EPA program is divided into two major subobjectives: (1) environmental assessment, the purpose of which is to determine the environmental impact of the energy technology, and to design a program for the development of control technology as necessary to reduce this impact; and (2) control technology development, in which the program designed as part of the environmental assessment activity is carried out.

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In view of the significance of the environmental assessment effort in defining control technology needs, this paper first addresses the methodology of conducting environmental assessments, and the status of the assessment of fluidized-bed combustion. The paper then summarizes some of the recent results of the fluidized-bed combustion control technology development effort.

In summary, it is apparent from available data that fluidized-bed combustion may be expected to control emissions of SO_2 and NO_x to below the levels required by the existing EPA New Source Performance Standards for large conventional coal-fired boilers. Particulate control adequate to meet the EPA emission standard for conventional coal boilers has not been demonstrated, either for atmospheric or pressurized fluidized combustors. In the case of atmospheric systems, particulate control will likely be similar to that for a conventional boiler burning low-sulfur coal; control at high temperature/pressure to meet conventional boiler emission standards in pressurized fluidized combustors will require control technology which has not yet been demonstrated. Data on emissions and control of potential pollutants other than SO_2 and NO_x (including those in liquid, solid, and air streams) are not adequate to allow firm conclusions regarding the emission levels of these potential pollutants. One of the first priorities of this EPA program is to identify emission levels for all potential pollutants from fluidized-bed combustors and, where standards or guidelines do not already exist, to try to define the degree of control required.

ENVIRONMENTAL ASSESSMENT

From a practical standpoint, the primary objective of the environmental assessment activity is to assure that an adequate research data base is available to support the development of standards and guidelines by EPA's regulatory offices. A related objective is to design EPA's control technology R&D program. The development of an adequate research data base to support standards/guidelines will be accomplished through: (1) comprehensive analysis of emissions from existing units; (2) engineering evaluation of available data on emissions; and (3) evaluation of data on the performance of available control devices/options. Design of the control technology R&D program will be accomplished by comparing the results of the comprehensive analyses of emissions with emission goals established based on health and ecological effects, independent of the specific energy technology.

The environmental assessment strategy is divided into six steps: (1) Identification of current process and environmental background, including a study of process flow sheets, status, and schedules; identification of possible emission sources throughout the process, considering all media; projection of possible emissions by means of theoretical calculations and engineering considerations; listing of potential pollutants; and collection of health/ecological effects, transformation/transport, and related information for potential pollutants. (2) Development of environmental objectives based ultimately on health and ecological effects of possible pollutants, with the goals expressed in terms of acceptable emissions. Based upon the effects, pollutants are prioritized. The goals are independent of the energy technology. (3) Acquisition of environmental data, including comprehensive analysis of emissions from existing fluidized-bed combustion facilities. An analytical approach in stages is employed to determine, in the most cost-effective manner, which of the pollutants on the listings of potential pollutants are being emitted to all media from all process streams, and at what levels. (4) Assessment of available control technology, including identification of specific control technologies, evaluation of the cost of alternative degrees of control, and assessment of the environmental impact of the control process itself. (5) Analysis of environmental alternatives, to identify the optimum combination of control devices (for all pollutants and process streams), considering the trade-offs between cost and degree of control. (6) Identification of further data and technology needs, including recommendation of a control technology development program, and also indicating requirements for further health/ecological effects data, transport/transformation data, and emissions data.

Figure 1 indicates schematically the relationship between these steps.

The methodology that is being developed for conducting some of these steps is discussed below. The status of the fluidized-bed combustion environmental assessment is also discussed.

Identification of Current Background

EPA's primary environmental assessment contractor--Battelle-Columbus Laboratories--has completed an initial compilation of engineering, environmental, and cost data for the fluidized-bed combustion process. Battelle, GCA/Technology Division (Reference 3), and Westinghouse Research Laboratories have conducted studies to project possible emissions of compounds other than SO_2 and NO_x, based upon theoretical calculations and engineering considerations; the results suggest no specific environmental problems, but additional actual emission data are required to enable firm conclusions. Battelle and (in a separate program) the Research Triangle Institute (RTI) are compiling health and ecological data for possible pollutants.

A key activity within this environmental assessment step is an attempt to establish boundaries for the assessment by deriving a list of the compounds to be considered. Battelle has developed a list of 1093 substances, derived by considering: (1) elements and compounds known to be present in coal and limestone/dolomite; (2) substances known to be emitted from coal combustion/conversion processes; and (3) substances with a potential for formation during combustion and for which Threshold Limit Value (TLV) and Lethal Dose data are available. This list is currently being refined by suitable grouping and consolidation of the substances. In an independent effort, RTI developed a list of 650 substances, referred to as the Multimedia Environmental Goals (MEG) pollutant list for fossil energy processes. RTI used the following criteria in developing their list: (1) substances known or suspected as emissions from coal or oil processing; (2) all classes of substances represented; and (3) substances for which TLV or Lethal Dose data are available, or for which environmental standards/guidelines/criteria are proposed or promulgated, or which are on certain other EPA listings. The RTI MEG pollutant list is considered to represent the primary substances of concern in the environmental assessment effort. The need for any additions to the RTI list, based upon the Battelle list, is currently being evaluated.

Future efforts on this step will also include preparation of a Technology Overview Report, which will divide all variations of the fluidized combustion process into generic unit operations, and will include a technical and environmental evaluation of each unit operation.

Development of Environmental Objectives

The primary vehicle being utilized to systematically develop environmental goals is the Multimedia Environmental Goals (MEG) Chart (see Figure 2). Ambient-level goals are developed for each pollutant based upon health/ecological considerations, and are then converted to emission goals for subsequent comparison with actual emission measurements.

Basically, the MEG Chart is a format for presentation of the goals, and of the data necessary to enable derivation of the goals. Columns IA and IB in Figure 2 are process-specific emission goals based, respectively, on current and revised emission standards, and on existing and developing technology. Columns II, III and IV are process-independent ambient-level goals, or estimated permissible concentrations (EPC's), based (respectively) on: current or proposed ambient standards; toxicity considerations (where ambient standards do not exist); and mutagenic/carcinogenic/teratogenic considerations (in which case a "permissible" concentration must be estimated on the basis of acceptable risk rather than on the basis of zero, or minimal, effect). In Columns II, III and IV, EPC's are presented both from the standpoint of human health, and from the standpoint of ecological effects (plants, other animals). The types of models used to calculate EPC's for Columns IIIA and IV, based on TLV, LD_{50}, and other

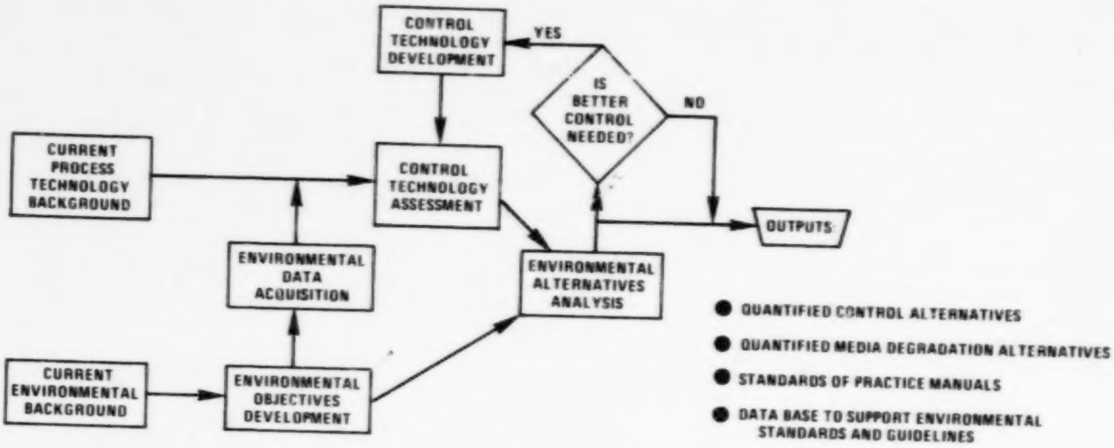
CONTROL TECHNOLOGY DEVELOPMENT
YES
IS BETTER CONTROL NEEDED?
NO
CURRENT PROCESS TECHNOLOGY BACKGROUND
CONTROL TECHNOLOGY ASSESSMENT
OUTPUTS
ENVIRONMENTAL DATA ACQUISITION
ENVIRONMENTAL ALTERNATIVES ANALYSIS
● QUANTIFIED CONTROL ALTERNATIVES
● QUANTIFIED MEDIA DEGRADATION ALTERNATIVES
● STANDARDS OF PRACTICE MANUALS
● DATA BASE TO SUPPORT ENVIRONMENTAL STANDARDS AND GUIDELINES
CURRENT ENVIRONMENTAL BACKGROUND
ENVIRONMENTAL OBJECTIVES DEVELOPMENT

Figure 1. Simplified block diagram showing relationship between steps of environmental assessment and control technology development.

	Emission-Level Goals					Ambient-Level Goals				
	I					II		III		IV
	Best Technology		Based on Ambient Factors			Current or Proposed Ambient Standards or Criteria		Toxicity-Based Est. of Permissible Concentration (EPC)[g]		Threshold Limit-Based EPC (for Carcinogen, etc)[a](h)
	A	B	C		D	A	B	A	B	
			Derived from Ambient-Level Goals (Cols II,III,IV)							
MEDIA	Existing Tech, NSPS, BPT[b]	Developing Tech, BAT[b] Revised NSPS	Based on Health Effects (c)	Based on Ecol. Effects (d)	Elimination of Discharge (EOD) Natural Background[e]	Based on Health Effects	Based on Ecological Effects	Based on Health Effects	Based on Ecological Effects[f]	Based on Health Effects
AIR, μg/m^3 (ppm vol)			3,900	12,400				7.1 (0.004)	12.4	3.9
WATER, mg/l (ppm wt)			41,400	500,000				41.4	500	58.5
LAND, μg/g (ppm wt)			80	1,000				0.03	1.0	0.12

(a) The MEG Goals are intended for broad planning purposes only and are not rigorous, absolute indicators of acceptable pollutant levels.

(b) BPT = Best Practical Control Technology; NSPS = New Source Performance Standards; BAT = Best Available Control Technology.

(c) Calculated by multiplying Column II A, or the lower value in III A and IV, by a selected dilution factor. The dilution factor selected for this example was 1000.

(d) Calculated by multiplying Column II B or Column III B by the assumed dilution factor.

(e) Calculated by multiplying natural background by assumed dilution factor.

(f) Where data are available on more than one plant or animal species, the data for the most sensitive species are used in Column III B.

(g) See Reference 9 for indication of type of models employed.

(h) Acceptable death rate should be defined and natural background levels should be considered; whereas TLV data usually consider physiological or behavioral effects, threshold limit in this case refers to genetic (carcinogenic, teratogenic, mutagenic, etc.) effects.

Figure 2. Example Multimedia Environmental Goals (MEG) chart for formaldehyde.[a]

available data, are suggested by Handy and Schindler (Reference 4); the EPC's in IIIB are based on the most sensitive applicable non-human species for which effects data are available. Further models for the completion of Columns IIIA, IIIB, and IV have recently been developed by RTI (Reference 5). In column IC, the estimated permissible ambient concentrations identified in Column II, III or IV are converted to emission level goals by multiplying the values in Column II, III or IV by the dilution factor assumed for converting source concentrations to ambient concentrations. All media (air, water, land) are represented on the Chart to assure that attempts to control emissions to one medium do not result in increased adverse impact on others.

The goals derived from the MEG Chart will be used to assist in deciding what pollutants should receive emphasis in the EPA program, and in planning the control technology development program for fluidized-bed combustion. It is emphasized that the MEG Chart is intended only for broad planning purposes; the limitations in available health/ecological effects data, and the simplifications necessary in the models used for calculating some of the EPC's, are such that the entries in Columns III and IV cannot be taken as rigorous absolute indicators of acceptable pollutant levels.

RTI is currently completing the MEG Chart for the 650 substances on the RTI list. The Chart will be updated as the substance list is refined. Among other future efforts required on the MEG Chart are: collection and analysis of available health/ecological effects data, and reconciliation of any differences, if possible; and derivation of improved models for calculating EPC's based upon available health/ecological data. Modeling needs include, for example: improved methods of employing TLV, LD_{50}, or other data to give air- and water-based EPC's; and definition and quantification of the chains by which soil concentrations enter human and ecological systems, so that land-based EPC's can be calculated. Attention will be given to estimating chronic pollutant effects, though much of the available data are for acute effects.

Comprehensive Analysis of Emissions

A comprehensive source sampling program is being undertaken in order to develop the emissions data base necessary for supporting environmental standards/guidelines, and to provide the actual emissions information necessary for comparison with the MEG Chart goals. In some cases, an ambient monitoring program may also be warranted.

In order to determine emissions of up to 650 substances (or more) on a cost-effective basis, a staged sampling/analysis approach has been proposed, consisting of three levels. Level 1 comprehensive analysis (Reference 6) involves initial comprehensive screening, using analytical techniques which sacrifice accuracy and compound specificity in order to identify possible problem areas in a cost-effective manner. Level 2 is designed based upon Level 1; more accurate, compound-specific techniques are used to explore the identified problem areas (Reference 7). Level 3 includes routine monitoring of those pollutants identified as specific problems in Level 2. Biological testing, as well as chemical analysis, is included. The Level 1/Level 2/Level 3 approach is being refined as experience is obtained using it.

Figure 3 indicates a typical sampling/analytical matrix for Level 1 comprehensive analysis. The analyses for organic reduced sulfur compounds, POM's, and toxic elements are technically Level 2 analyses, but are conducted concurrent with Level 1 since they are of known interest in fluidized-bed combustion.

To date, sampling of the type reflected by Figure 3 has been completed on four fluidized-bed units: a 6-inch (15 cm) i.d. atmospheric unit at Battelle; an 18-inch (46 cm) i.d. atmospheric unit at ERDA's Morgantown Energy Research Center, burning anthracite culm; a 2-foot by 3-foot, or 61 cm by 91 cm (cross section) pressurized combustor at the British Coal Utilization Research Association; and the 12-inch (31 cm) i.d. pressurized Miniplant combustor at Exxon Research and Engineering Company. Sampling is planned on other units as they become available, including the 30 MW Rivesville boiler.

Some analytical results are available from the samples taken from the Battelle and Morgantown units; these results are being evaluated. Considerable effort is being devoted to utilization of the MEG Chart goals to aid in the evaluation of the analytical results, and to help in the design of the Level 2 analytical approach based upon the Level 1 results.

Assessment of Available Control Technology

For the purposes of the EPA program, environmental control technology options are divided into four areas: (1) modification of process operating and design conditions; (2) pretreatment of input streams; (3) use of add-on control devices, such as a particulate removal device or a sorbent regenerator; and (4) minimization of the impact of solid residue disposal.

An approach is being developed to enable an orderly, reasonably uniform procedure for comprehensive assessment of available control alternatives. The approach will take into consideration: the degree of control possible for each important pollutant for each medium, as a function of device operating conditions and fluidized-bed combustion process operating conditions; the dollar costs of control (and the energy efficiency penalty of control) as a function of the degree of control for each device/option for each pollutant and process stream; the reliability of the device/option, taking into consideration the data and operating experience available on the device/option, and the theory/design principles behind it; the possible environmental impact of the control device/option itself; and any other factors that may become apparent during the development of the control technology evaluation approach.

As part of this task, Standards of Practice

Species, Pollutants	Sample Collection Techniques(a)	Analysis Method(b)	System Stream or Material						
			Stack			Waste from cyclone and bed	Coal Feed	Sorbent Feed	Leachate from Solid Waste (cyclone and bed)
			Particulates		Gas				
			Mid $>3\mu$	Fine $<3\mu$					
On-Line Continuous Gas Measurements									
CO_2	Cw	NDIR			x				
SO_2	Cw	IR or UV			x				
NO	Cw	NDIR or CL			x				
NO_2	Cw	NDIR or CL			x				
CO	Cw	NDIR			x				
O_2	Cw	PM or PE			x				
Total Gaseous Hydrocarbon	Cw	FID			x				
Integrated Gas Phase Measurements									
H_2S	Ig	GC			x				
COS	Ig	GC			x				
Disulfides	Ig	GC			x				
SO_3/H_2SO_4	St	GR/IC			x				
NH_3	St	KJ			x				
Cyanides	St	CO			x				
HCl	St	TI			x				
Fluoride, volatile	St	SIE			x				
Integrated Specimens for Subsequent Group Analysis									
Trace metals	SASS/Gs	SSMS	x	x		x	x	x	x
Major Elements (Fe, Al, Si, K, Ca)	SASS/Gs	OES	x	x		x	x	x	
Organic, by class	SASS/Gs	EX/LC/IR	x	x	x	x	x		
Organic-reduced, sulfur compounds	SASS/Gs	GC	x	x	x	x	x		
POM	SASS/Gs	GC/MS	x	x	x	x	x		
Proximate	Gs	ASTM D3172-73					x		
Radionuclides	SASS/Gs	Gross α and β assay	x	x		x	x	x	
Ultimate	SASS/Gs	ASTM D3176-74	x	x			x		
Sulfur forms	Gs	ASTM D2492-68					x		
Biological	SASS/Gs	In vitro	x	x	x	x	x	x	
Integrated Specimens for Subsequent Specific Analysis									
Toxic Elements (Be, Cd, Hg, As, Pb, Se, Sb, Te)	SASS/Gs	AA	x	x	x	x	x	x	x
Cl	SASS/Gs	CO	x	x					x
F	SASS/Gs	DI/CO	x	x		x			x
Na	Gs	AA					x		
Ca	Gs	AA/TI					x	x	
Mg	Gs	AA						x	
CO_3	SASS/Gs	GE	x	x		x	x	x	
SO_4	SASS/Gs	TI/IC	x	x		x	x	x	x
SO_3	SASS/Gs	SO_2 GE/CO	x	x		x	x	x	x
S	SASS/Gs	GE/TI	x	x		x	x	x	
NO_2	SASS/Gs	CO/IC	x	x		x	x	x	x
NO_3	SASS/Gs	CO/IC	x	x		x	x	x	x
C "Non Carbonate"	Gs	C				x	x	x	
Heating value	Gs	ASTM D2015-66					x		
Particle morphology	Gs/Ci	SEM				x	x	x	
Particle size	Gs/Ci	Sieve ASTM 410-38				x	x	x	
Particle mass	M5	Weight	x(c)	x					

(a)	
Cw	Continuous withdrawal through non-reactive line with mechanical filtration
Ig	Integrated grab sample of gas in glass bulb
St	Separate wet chemical train to collect gas (such as Method 6)
SASS	Source Assessment Sampling System (train used for suspended particulates, organics, and volatile trace elements)
Gs	Grab multiple samples riffled to reduce to 100 g representative sample
Ci	Cascade impactor in flowing stream
M5	EPA Method 5

(b)	
NDIR	Non-dispersive infrared
IR	Infrared
UV	Ultraviolet
CL	Chemiluminescence
PM	Paramagnetic
PE	Platinum Electrode
FID	Flame Ionization Detector
GC	Gas Chromatography
GR	Goksoyr-Ross
IC	Ion chromatography
KJ	Kjeldahl
CO	Colorimetric
TI	Titration
SIE	Selective-Ion Electrode
SSMS	Spark Source Mass Spectroscopy
OES	Optical Emission Spectroscopy
EX	Extraction
LC	Liquid Chromatography
GC/MS	Gas Chromatography with mass spectrography
AA	Atomic absorption
DI	Distillation
GE	Gas Evolution
C	Combustion
ASTM	American Society for Testing Materials Standard Method
SEM	Scanning Electron Microscope

(c) Coarse ($>10\mu$) and Filter ($<1\mu$) fractions included.

Figure 3. Example sampling/analytical matrix for Level 1 comprehensive analysis on fluidized-bed combustor.

Manuals will be prepared in support of EPA's regulatory offices, and will be updated as necessary.

Environmental Alternatives Analysis

The primary purpose of environmental alternatives analysis is to identify the optimum combination of control options for plants representing all variations of the fluidized-bed combustion process. This analysis will consider: (1) the "hazard" associated with the levels of each pollutant in each stream, calculated by comparing the health/ecological effects goal for each pollutant (developed via the MEG Chart) with the actual emissions observed from comprehensive analysis; and (2) the cost of alternate degrees of control available with alternate control options, as defined in the previous step. The analysis will further be employed to identify problem pollutants and, based upon the degree of "hazard," to: (1) rank effluent streams within each fluidized combustion process variation; and (2) compare the different variations.

The primary tool currently under development to enable environmental alternatives analysis, is the Source Analysis Model (SAM). SAM methodology is being developed under EPA contract by Aerotherm Division of Acurex Corp. Basically, the SAM approach involves calculation of a normalized degree of hazard for each pollutant in a selected stream by computing the ratio of the concentration of the pollutant in the stream to the goal concentration indicated in the MEG Chart; i.e.,

degree of hazard for pollutant i in stream k =

$$\frac{C_{ik}}{(C_{ik})\text{MEG}}$$

where C_{ik} is the observed concentration and $(C_{ik})\text{MEG}$ is the emission goal read from Column IC or ID in the MEG Chart for pollutant i. The total degree of hazard for a stream can then be calculated by summing over all pollutants in the stream; the degree of hazard for a plant can be calculated by summing all streams. If the performance of alternative individual control options for each stream is known, the SAM can be used to find the control option, or combination of options, which minimizes the degree of hazard for any one stream or for the total plant.

Three versions of the SAM are under development by EPA's Industrial Environmental Research Laboratory/RTP, varying according to the level of detail in the model. These versions are:

- SAM/IA, to be used for initial rapid effluent concentration screening, using MEG goals based upon more readily available, acute toxicity data.
- SAM/I, to be used for more rigorous screening, using MEG goals based upon estimated chronic effects.
- SAM/II, a general model to be used for evaluating any U. S. regional site alternative.

Design of R&D Program for Control Technology

Additional control technology required will be identified based upon the results of the environmental alternatives analysis. If--after comparing the MEG health/ecological goals with the actual observed emissions from fluidized combustion units and with the capabilities of currently envisioned control technology--the alternatives analysis indicates an unacceptable hazard for a specific pollutant/stream which cannot be reduced at practical control cost, then new control alternatives, or further development of current alternatives, will be identified in order to reduce the hazard to acceptable levels. Control alternatives may fall into the four categories listed previously: (1) modification of process operating and design conditions; (2) pretreatment of input streams; (3) use of add-on devices; and (4) techniques for reducing the impact of solid residue disposal.

Additional information needs may be identified in areas other than control technology; e.g., additional health effects data may be necessary, or further effort may be required in the development of environmental assessment methodology.

Development of Data Base for Standards/Guidelines

One major product of the environmental assessment effort will be the development of a research data base adequate for supporting environmental standards and guidelines for all variations and applications of the fluidized-bed combustion process. Standards Support Plans and Standards Development Research Data Base Reports will be prepared and updated as warranted in support of EPA's standards-setting offices.

CONTROL TECHNOLOGY DEVELOPMENT

In parallel with the fluidized-bed combustion environmental assessment effort, a significant program is being conducted by EPA to develop suitable environmental control technology (References 1 and 2). The control technology effort is too broad to be described in detail here, but some important recent results are listed.

Modification of Process Operating/Design Conditions

Testing is underway on the 0.63 MWe pressurized fluidized-bed Miniplant combustor, built under EPA sponsorship at Exxon Research and Engineering Co. (Reference 8). Figure 4 shows some recent results indicating SO_2 removal in the pressurized (9 atm, or 910 kPa) bed as a function of sorbent feed rate. The figure shows that the dolomite used in this study is a more effective sulfur sorbent than is the limestone (on the basis of the sorbent feed rate, expressed as the ratio of moles of calcium in the sorbent feed to the moles of sulfur in the coal feed). Also, in a pressurized system, limestone becomes more effective when the bed temperature is high enough to result in calcination of the calcium carbonate.

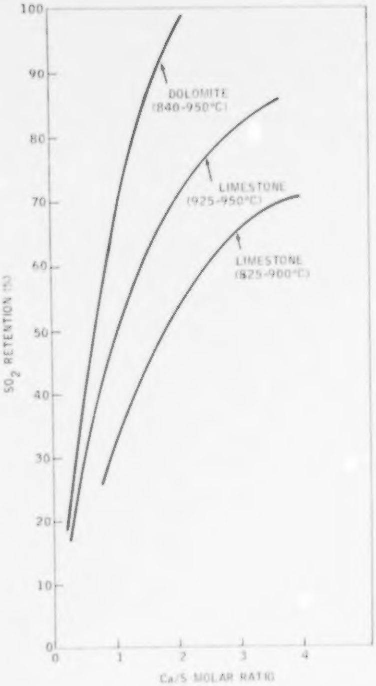

Figure 4.

Sulfur capture results from the Miniplant fluidized-bed combustor at 9 atm (910 kPa).

The Miniplant combustor NO_x emissions at 910 kPa are shown in Figure 5 as a function of excess air. As indicated, the emissions are consistently well below the EPA New Source Performance Standard of 0.7 lb/10^6 BTU (0.30 g/10^6 J).

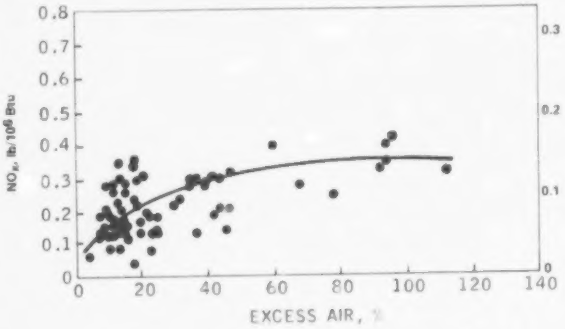

Figure 5. NO_x emissions from the Miniplant fluidized-bed combustor at 9 atm (910 kPa).

Pretreatment of Input Streams

Precalcination of the limestone feed to pressurized fluidized combustors is being studied as a means for reducing sorbent requirements, and thus reducing the quantity of solid residue. Figure 6 shows the results of a limestone precalcination study on the Miniplant at 9 atm (910 kPa). Figure 6 is similar to Figure 4, except that three data points are included indicating the performance of precalcined limestone. As shown, precalcination can make the limestone as effective as the dolomite on the basis of the calcium-to-sulfur molar ratio.

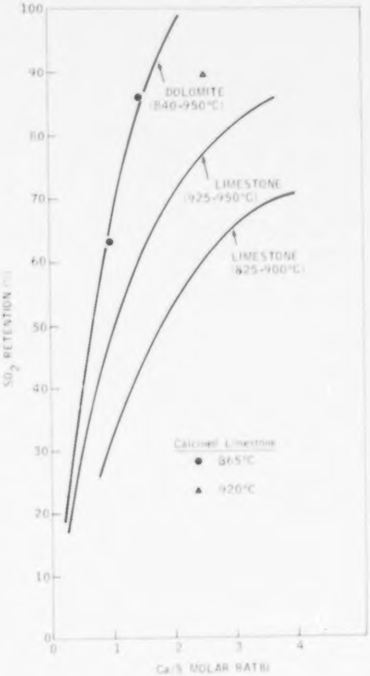

Figure 6.

Limestone precalcination results from the Miniplant fluidized-bed combustor at 9 atm (910 kPa).

Add-on Control Devices

Among the particulate control devices to be tested in the near future are: a 500 acfm (14 cu. meters/min) Ducon high temperature/pressure granular bed filter, which has been installed on the Miniplant and is currently undergoing shakedown; an Aerodyne cyclone to be tested on a 500 acfm (14 cu. meters/min) high temperature/pressure particulate control test stand now being installed by Westinghouse Reaearch Laboratories; and 25-3000 acfm (0.7-85 cu. meters/min) conventional scrubbers, fabric filters, and electrostatic precipitators to be tested on the flue gas from ERDA's Rivesville boiler using trailer-mounted, mobile devices developed by EPA. Also, EPA is interested in complete characterization of any devices installed on large fluidized-bed combustion facilities, for example, the in-system electrostatic precipitator on the Rivesville boiler, and the baghouse planned for the Georgetown University boiler. Future plans include the possibility of modifying existing control devices, or installing new devices, on large fluidized boiler installations.

Another add-on option being studied is sorbent regeneration, which should reduce fresh sorbent requirements and hence the quantity of solid residue. The Miniplant combustor/regenerator system has been successfully operated for a sustained shakedown run of 100 hours at 9 atm (910 kPa), with continuous regeneration of the sorbent. The run demonstrated that it is technically feasible to regenerate the sorbent by means of reductive decomposition, and that regeneration can reduce fresh sorbent requirements to only 15 to 20 percent of that which would be required to maintain the same degree of sulfur control without regeneration. In a project co-funded by ERDA and EPA, a semi-continuous 10-cycle combustion/regeneration run was also conducted by Argonne National Laboratory using a 6-inch (15.2 cm) i.d., 8 atm (810 kPa) fluidized combustor and a 4.25-inch (10.8 cm) i.d., 1.5 atm (153 kPa) regenerator. The initial portion of this test is described in Reference 9. Based upon their results, Argonne calculated that, with regeneration, fresh sorbent requirements could be reduced to only about 20 percent of that necessary without regeneration. This conclusion is consistent with the Exxon results. Although regeneration is technically feasible, further work is necessary to optimize the regeneration step, and to define its range of economic feasibility.

Solid Residue Disposal

Westinghouse Research Laboratories has been conducting laboratory "shake" tests--in which small quantities of fluidized-bed combustion solid residue are shaken in a flask containing water--in order to obtain preliminary information on leachate characteristics. Ralph Stone and Co. is conducting laboratory lysimeter column tests. Further shake testing, lysimeter testing, and field cell testing are necessary before firm conclusions can be drawn regarding the environmental impact of the residue, and such testing is planned. Figure 7 summarizes some of the results of the Westinghouse shake testing. Prior to the availability of MEG goals, Westinghouse employed two other "goals" against which to compare their leachate data: (1) drinking water standards; and (2) the leaching properties of natural gypsum. It should be emphasized that these "goals" were selected only in an effort to put the data into perspective; they are not absolute indicators of whether the fluidized combustion residue leachate is environmentally acceptable or unacceptable.

CONCLUSIONS

An effort is underway to develop the methodology for environmental assessment of fluidized-bed combustion (and of other developing energy technologies). The results of the environmental assessment will be used in two ways: (1) from the regulatory standpoint, the results will be used to support environmental standards and guidelines; and (2) from the R&D standpoint, the results will be used to design a control technology research and development program, in order to enable future standards to be set in accordance with any more stringent objectives that may be established by EPA's standards-setting offices. Results from the fluidized combustion environmental assessment are only starting to become available. Some control technology data are available, largely for the current criteria pollutants.

ACKNOWLEDGMENT

The environmental assessment methodology described in this paper is being developed under the guidance of Mr. R. P. Hangebrauck, Director, Energy Assessment and Control Division, Industrial Environmental Research Laboratory/RTP.

Sample	Process	Sorbent	Environmental Parameters						
			Heat Release	Trace Metal	Total Dissolved Solids	Sulfide	pH	Sulfate	Calcium
Spent Sorbent (bed material)	Pressurized System once - through	Limestone	ND <0.2°C*		▩		▩ pH = 12.5	▨	▩
"	Pressurized System once - through	Dolomite	ND <0.2°C		▨		▩ pH = 11.9	▨	▨
"	Atmospheric System once - through	Limestone	ND <0.2°C		▩		▩ pH = 12.3	▨	▩
Flyash (fines of sorbent/ash)	Pressurized System once - through	Limestone	ND <0.2°C		▨		▩ pH 8 to 11	▨	▨
Mixture of Spent Bed Sorbent and Flyash	Pressurized System once - through	Limestone	ND <0.2°C		▨		▩ pH 8 to 10	▨	▨
Gypsum	Natural	–	ND <0.2°C		▨		pH = 7.4	▨	▨

▩ Do Not Meet Either The Drinking Water or Gypsum Leachate Criteria

▨ Pass Gypsum Leachate Criteria But Not Drinking Water Standards

☐ Pass Both Drinking Water and Gypsum Leachate Criteria

* ND <0.2 C indicates not detected with 0.2 C being the minimum detection limit.

Source: Westinghouse Research Laboratory

Figure 7. Summary of some results from Westinghouse shake tests on fluidized-bed combustion solid residue.

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RESEARCH AND DEVELOPMENT PROGRAMS FOR POLLUTION CONTROL FROM OIL SHALE EXPLOITATION

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INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is interested both in oil shale research and development projects for which it provides funds and in projects funded by other governmental and industrial sources. Many EPA projects themselves involve interaction between EPA and other agencies, and it is anticipated that future EPA projects will also involve industry. Research provides data for defining ecological and health effects and for developing cost-effective control technology that can be used by government and industry to minimize the degradation of the environment.

The five major projected areas of in situ oil shale research and development are as shown in Table 1.

TABLE 1. IN-SITU OIL SHALE RESEARCH AND DEVELOPMENT

In-Situ Major Projects	Involved Performer	Location
Antrim Shale	Dow	Midland, MI
True In-Situ	Talley-Frac	Rock Springs, WY
Solution Mining	Equity	Rio Blanco County, CO
Vertical Modified In-Situ	Occidental	Debeque, CO
Vertical Modified In-Situ	Geokinetics	Unitah County, UT

The tempo of oil shale development has picked up with Occidental Oil Shale, Inc.'s assumption of the role of project operator for the federal tract C-b lease. Occidental and its partner, Ashland Oil, have released a development schedule which involves construction resumption on the tract as soon as the current lease suspension expires in September 1977. The upsurge in activity is a result of Occidental's modified in situ production technology that shows improved economics and reduced environmental problems when compared with surface retorting. Due to the greatly reduced capital requirements of the in situ project, no governmental assistance in the form of loan guarantees or price stabilization is required. For the plant coming on-stream in 1983, oil production rates are projected to be 57,000 BPD at an estimated cost of $8 to $11/barrel.

As a result of research and development by government and industry, primarily during the past three decades, a processing sequence of underground room and pillar mining and surface retorting has evolved for production of shale oil. The surface retorting methods that have reached the point of potential industrial scale-up in the U.S. include: (a) the TOSCO II and Lurgi-Ruhrgas processes that employ recycled hot solids for heating, (b) the Paraho Direct Mode process that has an internal combustion zone within the retort, and (c) the Union Retort B, Superior Oil, and Paraho Indirect Mode processes that have external, fuel-fired furnaces as heat sources.

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The TOSCO II and Paraho Direct Mode processes have attained production capacities in the range 500 to 1000 tons/day and could, therefore, be considered amenable to early scale-up to a 10,000-ton/day commercial module. This is probably also true for the Union Retort B, based upon the Retort A design that operated successfully 20 years ago at 1200 tons/day.

A Lurgi-Ruhrgas pilot plant (West Germany) with 16 to 25 tons/day as the nominal capacity has been used to process Colorado shale, and a 4000-ton/day demonstration unit has been designed. A Superior Oil pilot plant (Cleveland, Ohio) nominally producing 240 tons/day is currently being tested and a 24,000-ton/day commercial plant has been proposed. A 1-ton/day hydrogasification unit producing pipeline quality gas from oil shale has also been constructed and operated for several years by the Institute of Gas Technology (IGT) in Chicago.

All of the other oil shale projects developed to varying stages within the last few years continue only at maintenance levels. Some of the problems hindering development have been resolved, and positive government action on financial assistance, environmental problems, and energy policy may be required. Within the federal government, the creating of a new Department of Energy and formulation of a national energy policy is taking precedence over specific energy projects. At this time, it is not known how much importance the present Administration gives to the development of an oil shale industry.

Table 2 lists some of the areas that have been funded all or in part by EPA. Groundwater, surface water, air emissions, and solid wastes have all received environmental and health consideration to varying degrees.

TABLE 2. EPA OIL SHALE RESEARCH AREAS

Air Studies

Emissions from gasoline derived from coal and shale oil
Impact on ambient air quality
Measurement of particulates, SO_2, and NO_x
Emission from conversion facilities
Pilot balloon observations
Smog chamber studies of atmospheric chemistry of organic- and nitrogen-containing emissions
Inorganic compounds in particulates

(continued)

TABLE 2 (continued)

Quality assurance program for air-monitoring laboratories
Air quality monitoring
Meteorological data
Health effects of combustion products

Water Studies

Aquatic terrestrial ecosystem study on the White River (with Bureau of Reclamation)
Surface water quality monitoring (with USGS)
Impact on western Colorado water resources
Water quality hydrology affected by oil shale development
Toxic effects on the aquatic biota
Design groundwater monitoring system
Water quality monitoring (surface)
Groundwater monitoring

Solid Waste Studies

Vegetative stabilization of spent oil shales
Components of final aqueous effluents and solid wastes
Productive uses of wastes from mining and processing
Vegetative stabilization of spent Paraho oil shale

Assessments

Evaluation and development of an environmentally acceptable shale oil industry
Environmental assessment and data acquisition
Program support for synfuels
Technology assessment of western energy resource development
Overhead remote sensing
Water management alternatives
Monitoring quality assurance

PRESENT RESEARCH--ACCOMPLISHMENTS AND IMPACT

Interagency participation in and funding of contract research and development is an indication of the wide spectrum of interests government agencies have in oil shale programs. As increasing attention is given to energy development and environmental control technology, EPA, in cooperation with other agencies, will keep pace with expanding programs in grant and contract research applied to oil shale.

The Industrial Environmental Research Laboratory-Cincinnati supports coordinated, interagency oil efforts by administering an R&D program covering environmental assessment and development of extraction and process control technology. Reports on recent activities are forthcoming which cover preliminary assessment of impacts from oil shale development, overview descriptions of each of the eight leading processes under development, and results of a sampling program conducted during recent Paraho retorting operations. A major project to develop spent shale disposal and revegetation technology is progressing with construction of test facilities nearing completion. All these activities are oriented toward defining and/or developing timely, effective environmental control technology as needed for the industry's growth.

Much of the EPA monitoring research is done at its Environmental Monitoring and Support Laboratories (EMSL) at Las Vegas, Nevada; Cincinnati, Ohio; and Research Triangle Park, North Carolina. Las Vegas activities include western regional air monitoring, groundwater monitoring and techniques development, and overhead monitoring. Cincinnati EMSL stresses water techniques development and quality assurance. Research Triangle Park is developing energy-related air monitoring quality assurance support and air pollutant measurement and instrumentation research.

EPA participates in interagency funding in several programs. For example, a surface water quality monitoring program in western Colorado has been in progress since 1975 and is being done by the U.S. Geological Survey (USGS) with EPA pass-through money. Another USGS project includes EPA's Las Vegas Environmental Research Center work on nonpoint-source water pollution monitoring approaches and techniques. The objective is to develop and assess ground and aerial monitoring of extractive mining nonpoint-source pollution. Other examples of cooperative programs include the Energy Research and Development Administration's (ERDA) development of aqueous effluent instrumentation and methods for energy-related sources, National Aeronautics and Space Administration's (NASA) technical support for western energy-related environmental assessment/overhead monitoring method development, and National Bureau of Standards' (NBS) water pollutant analyses instrumentation.

EPA is studying the fate in fresh waters, groundwaters, and air of specific pollutants resulting from oil shale development. The Athens Laboratory is studying the fate of specific pollutants in fresh waters. The R. S. Kerr Environmental Research Laboratory (ERL) is identifying the transport and fate of oil shale-related pollutants in groundwaters. EPA Region VIII is providing for the maintenance of an air quality monitoring network to continue to define long (5-year) baseline data information.

Health effects of oil shale development are being investigated by the U.S. Navy, National Institute for Occupational Safety and Health (NIOSH), ERDA, and EPA. The Research Triangle Park Health Effects Research Laboratory of EPA is assessing human exposure-effects relationships and evaluating hazards to man under controlled experimental conditions.

The NIOSH studies address the occupational health of oil shale workers, and the Navy research concentrates on health effects associated with the burning of fuel oil derived from shale. The work being done by ERDA and EPA is in the general fields of toxicity and carcinogenicity.

By far the most widespread environmental research efforts are in the field of ecological effects. Agencies involved in this field include ERDA, the U.S. Department of Agriculture (USDA), the U.S. Bureau of Mines, USGS, the U.S. Navy, and EPA. Emphasis has been placed on revegetation, water, and, to a lesser extent, on land use. Atmospheric research has been conducted in the general fields of measurement and monitoring.

Current activity by the EPA Duluth Laboratory includes oil shale-related fresh water ecosystem effects. The acute and chronic toxicological effects on fresh water organisms and ecosystem impacts of pollutants and complex effluents released by oil shale processes will be determined. Region VIII of EPA will develop a comprehensive information profile for major fresh water aquatic environments that could be affected by oil shale development. This will be accomplished through a number of biological studies.

Among the other agencies funding research in biological transport phenomena are ERDA and the U.S. Fish and Wildlife Service. ERDA areas of interest include repair of damaged cells, cell regulatory systems, molecular damage of DNA, and proteins. The Fish and Wildlife Service is investigating the impact of western energy development of water sources and subsequent effects on fish and wildlife.

EPA is also interested in work being done by the American Petroleum Institute. Research in both biological and medical science related to shale oil processes is in progress.

Interagency participation is exemplified by the cooperation between EPA and USDA in assessing impacts of mining and controlling adverse effects on forest, range, and related fresh water ecosystems.

PLANNED RESEARCH

Extraction process gaseous emissions, wastewater effluents, and spent-shale wastes will be identified and characterized. The availability of technologies to effectively control pollution from resource extraction will be assessed. Oil shale in situ and surface processing and combustion will be evaluated through continuation of environmental characterization of emissions, effluents, and solid wastes. The multimedia pollution from oil shale mining, processing, and combustion will be studied to assess control processes available and under development. The identification of environmental impacts of oil shale development will augment development by ERDA, the Navy, the Department of the Interior, and industry. Various related studies--such as characterization, monitoring, pollutant transport, health effects, and ecological effects--will be conducted.

EXPECTED OUTPUTS

The environmental research and development results for the near term are expected to be characterization, control technology, and measurement and monitoring protocols for oil shale development. In situ processing, extraction, surface retorting, refining, and combustion are included in current oil shale research activities. The Navy, ERDA, and industry are conducting the major process developments, and it is anticipated that major environmental activities will be associated with process development. Medium term environmental research between 1980 and 1985 is expected to include continued emphasis on control technology, transport processes, health effects, and ecological effects. Long-range research and development beyond 1985 will be required for updating health and ecological effects and control technology requirements.

CONCLUSIONS

EPA has an active role in many areas of oil shale research and development. Project funding responsibilities are shared with other agencies, a few of which are highlighted here. Oil shale research and developments by others are of interest to EPA so that duplication can be avoided and active project results can be applied to environmental assessment and control technology development. The interagency approach to the development of the oil shale resource allows a multi-faceted approach and assessment, providing for less expenditure by the Nation.

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ENVIRONMENTAL CONSIDERATIONS OF SYNTHETIC FUELS

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INTRODUCTION

With a new and vigorous energy policy, it is apparent that our nation's vast coal reserves will not be neglected. Synthetic fuels represent one option offering solutions to problems associated with coal utilization. However, while promising an environmentally clean fuel, solutions in transportation, and improved economics (especially in allowing use of present oil/gas-based energy conversion systems), synthetic fuel production creates new environmental problems. Since energy is desirable only as it maintains and improves the quality of life, consequential deleterious environmental effects must be lessened, removed, or avoided.

Within the Federal government, the Environmental Protection Agency has the primary responsibility to assess the environmental factors of energy technologies and to develop and/or aid the development of controls to protect the environment from adverse effects. Development of energy systems without early consideration of the environmental factors may result in last-minute and, therefore, costly and inefficient add-on controls. A more rational approach is to begin with a lower level of environmental concern during initial bench-scale process development and continually increase environmental awareness until a comprehensive program is realized during pilot and larger operations.

HOW THE SYNTHETIC FUELS ENVIRONMENTAL PROGRAM WAS DEVELOPED

The environmental factors in the production and utilization of synthetic fuels from coal are an important responsibility of the Fuel Process Branch of EPA's Industrial Environmental Research Laboratory (IERL-RTP). This branch (including its predecessor names) has had a significant role in evaluating the environmental aspects of synthetic fuels for more than a decade. Earlier programs were concerned primarily with historical surveys, pollution control problem definitions, isolated research studies, and pioneering efforts. EPA has attempted to project the future course of the industry and plan environmental programs on a technical evaluation basis. This has been accomplished in earlier contractual arrangements that: (1) sponsored the most progressive synthetic fuels environmental research in this country in an attempt to add direction toward environmental integrity in these efforts, and (2) utilized the available data base to characterize aspects of the synthetic fuels industry that had to be studied regardless of the direction the industry might take. An example is the characterization of the primary feedstock, coal.

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One objective was to do as broad a survey as possible of all avenues of application, looking at proposed research and ongoing projects to ensure that: (1) all predictable environmental impacts had been considered and (2) most areas of environmental importance common to a number of processes were grouped together to insure greater efficiency in the environmental approach.

Following problem definitions, the next step involved structuring a coherent, comprehensive, and goal-oriented program. EPA's present synthetic fuels program currently comprises a much more comprehensive approach addressing the broad scope of environmental assessment and control technology development for high- and low-Btu gasification and liquefaction. Associated, longer-term contractual arrangements emphasize data acquisition and are supported by research grants to do fundamental studies.

Synthetic fuels research is being coordinated within the Fuel Process Branch with closely related programs in both physical and chemical coal cleaning. Studies of fuel contaminants also provide close parallels; for example, the denitrogenation and desulfurization of petroleum products. At the next level, within the Energy Assessment and Control Division, there is coordination with conventional coal combustion and more advanced systems such as fluidized bed combustion.

With some modifications to internal structure, and increased emphasis on data accumulation, the major thrust of the EPA Synfuels program still follows a formulation derived well before this fiscal year.[1] Environmental assessment activities still include high-Btu gasification, low-Btu gasification, liquefaction, and general support with continuing characterization of input material. In control technology development, the major contract areas are divided to cut across process technology lines; thus, each prime contractor is responsible for low- and high-Btu gasification and liquefaction for his respective work area. The major work areas divide a given technology roughly along the following lines: converter output streams, products and byproducts, and pretreatment and waste. These categorizations should also improve parallelism with the directions being taken by others (such as the Energy Research and Development Administration) doing primary energy research.

Table 1 sketches the EPA programs and contractors committed to date. These contracts will be carried to a state of completion to include: (1) plans for full-scale industry data acquisition, (2) background data for the establishment of Federal standards, (3) investigation of existing and proposed control technology including equipment operation, and (4) evaluation of the impact of both data and recommendations on the industry's establishment. The program attacks environmental problems at every level: laboratory, pilot testing, and full-scale field testing.

TABLE 1. IERL-RTP SYNTHETIC FUELS ENVIRONMENTAL PROGRAM

Environmental Contract Area	Organization
Prime Contracts	
Environmental Assessment High-Btu Gasification	TRW Systems
Environmental Assessment Low-Btu Gasification	Radian Corporation
Environmental Assessment Liquefaction	Hittman Associates, Inc.
Control Technology Development--Converter Outputs	Hydrocarbon Research, Incorporated
Control Technology Development--Products/Byproducts	Catalytic, Incorporated
Control Technology Development--Pretreatment, Water, and Wastes	Pullman-Kellogg
General Support	Cameron Engineers
Research Grants	
Pollutants from Synthetic Fuels Production	Research Triangle Institute
Raw and Acid Gas Cleanup	North Carolina State University
Water Treatment for Synfuels Processes	University of North Carolina
International Agreements	
Environmental and Engineering Evaluation of the Kosovo Coal Gasification Plant	Rudarski Institute, Belgrade & REMHK Kosovo Yugoslavia
Parallel Support Research	
Fuel Contaminants Removal	Battelle Columbus Laboratories
Characterization of Coal and Coal Residue	Illinois State Geological Survey
Technical/Economic Study of Gas Cleanup Systems for Combined Cycles	United Technologies Research Center
Wastewater Control Alternatives	Water Purification Associates

COOPERATIVE EFFORTS PROMISE COMPREHENSIVE ENVIRONMENTAL RESULTS

An important step in coordinating the knowledge and expertise of those associated nationwide, and globally, with the problems of synthetic fuels is the initiation of interagency agreements. This type of cooperation, for example, with the ERDA and the National Institute of Occupational Safety and Health (NIOSH), allows a more complementary mesh of environmental and energy concerns. Multiagency data acquisition and analysis will greatly enhance optimization: selection of the best controls at the lowest cost and with the greatest expediency to meet our energy and environmental requirements. EPA's cooperation with those in the forefront of developing technology offers the best chance for the industry to emerge with minimal necessary constraints.

Mutual participation has already begun under an Interagency Energy Accomplishment Plan.[2] Control problem definition studies for in situ gasification were successfully initiated jointly by IERL-RTP and ERDA and have since been transferred to EPA-IERL-Cincinnati. An environmental and technology status report for this effort has been published.[3] IERL-RTP also participates in an ongoing study for water treatment at demonstration plants and in the environmental test programs and plans at such facilities as the ERDA Morgantown and Grand Forks research centers. The liquefaction demonstration plant at Fort Lewis has been visited, and environmental test plan recommendations by EPA are near completion. Agreements are also evolving for EPA involvement at industrial sites, especially those with ERDA program involvement, where full-scale coal conversion is either in operation or soon to be operational.

EPA has assisted by reviewing documents written for or by other agencies--e.g., the Coalcon draft environmental analysis report[4] for that demonstration plant and the NIOSH draft guidelines for coal gasification pilot plants.[5]

Another agreement has been signed for work in Yugoslavia on a Lurgi coal gasification plant. Several meetings have been held with the Yugoslavian participants to discuss the EPA data acquisition program. The latest meeting was in April and several other agencies and private organizations attended the discussions (e.g., ERDA, the Institute of Gas Technology, Radian, U.S. Bureau of Mines, Peabody Coal Co., Catalytic, and Hydrocarbon Research, Inc.).

EARLY EPA RESEARCH ACCOMPLISHMENTS FOCUS ON PROBLEMS AND SOLUTION POTENTIALS

The involvement of the present EPA staff with coal conversion and utilization programs can be traced back at least to publication of a study in 1965 on the feasibility of coal desulfurization under the old Division of Air Pollution.[6] Some interim studies are interesting in their multiformity, such as: (1) an extensive 1970 report on the technological and economic advantages of advanced power cycles,[7] especially for nonpolluting fuel production (combined cycle work is being continued in conjunction with an overall impact study for fuel gases from advanced gasification systems), and (2) a series of experimental undertakings completed in 1973 investigating the reaction mechanisms of coal pyrolysis through the method of nonisothermal reaction kinetics. (A final report in 1973 was produced on the gasification of fossil fuels under oxidative, reductive, and pyrolytic conditions.)

Early emphasis was also placed on coal characterization, since there was a good foundation of both expertise and data in this area and because feedstock analysis is absolutely necessary for the evaluation of environmental impact. With EPA funding, such agencies as the U.S. Bureau of Mines and the Illinois State Geological Survey produced a very comprehensive description of U.S. coals, particularly with respect to the sulfur content, washability characteristics, trace element makeup, and availability.

Also, a significant number of reports have been concerned with the projections of types and quantities of potential pollutants which could be associated with coal conversion. Results have included tabulations, prioritizations, and chemical/physical/toxicity characterizations of various elements and compounds. Reports on potential emissions from coal and oil extraction processing, on trace constituents from gasification processes, and the continuing multimedia environmental goals evaluations are good examples.

Attempts have also been made to characterize the scope and complexity of the industry itself; e.g., a series of reports on eleven gasification and liquefaction processes, the potential pollutant problems associated with each primary module and effluent stream, and a summary report comparing all conclusions. Additional familiarization with environmental problems of synthetic fuels plants was gained though a series of field trips to overseas industrial sites including the South African SASOL plant, the Scottish Westfield Research Center, and the Koppers-Totzek and Winkler gasification processes in Turkey.

One highly productive mechanism for a variety of projects has been the award of tasks under multioptional contracts. Some typical tasks obtained in this manner include: (1) a state-of-the-art review of fuel contaminants concerned primarily with factors of environmental importance; (2) environmental test units designed for studying gasification and liquefaction problems; (3) discussion of a SASOL-type process for gasoline, methanol, SNG, and low-Btu gas from coal; and (4) a compilation of Federal regulations, both source and ambient, for all media, and relation of regulations to the coal conversion industry.

The IERL-RTP has sponsored, for the past few years, symposia on the Environmental Aspects of Synthetic Fuels Technology. The proceedings of these symposia have been published and contain discussions of the state-of-the-art propositions for solutions to synfuels environmental problems. EPA coal conversion program personnel and contractors have also sponsored and closely participated in the Advanced Fossil Fuel Sector group meetings which include participation by a number of Federal agencies.

ACHIEVEMENT OF PROGRAM GOALS BEGINS WITH NEW ACCOMPLISHMENTS

The most obvious accomplishment of EPA's coal conversion efforts is the increased environmental awareness of both process developers and the public of the potential problems and initiation of efforts to mitigate future problems. To extend the accomplishments discussed above to specific situations and more direct utilization, an overall program plan has been established, contracts awarded, and work initiated which will fill out the research data base and assessments for environmental control.

A summary of performance to date begins with actions taken by the primary environmental assessment and control technology development contractors.

Environmental assessment of low-Btu gasification has begun with (1) a work plan and technology overview, (2) preparation for data acquisition at coal conversion plants including Kosovo, Yugoslavia, (3) a review on the use of computer process simulation to predict performance of acid gas removal and its associated environmental problems, and (4) the design of a sampling train for use at proposed test sites.

Low-Btu gasification sites in the United States have been located and their operators contacted. A series of tests is to be run during 1977 at four sites, both Federal and private. At one of the sites, operations will be coordinated with an ERDA-funded program. General and specific test manuals are being prepared. To assess analytical techniques, grab samples of ash, particulates, gases, liquors, and tar from several U.S. plants have been analyzed in the laboratory. In addition, a technical information system for project support has been established with over 9,500 citations.

The coal liquefaction environmental assessment progress includes preparation of an overview document, pilot plant site visits including the Solvent Refined Coal pilot plant at Fort Lewis, combustion testing of both coal and solvent-refined coal (in Plant Mitchell, Georgia), and ASTM petroleum tests and gas chromatographic studies on synthetically produced liquid fuel samples for potential gas turbine fuels evaluations by the National Aeronautics and Space Administration.

Control technology development for fuel conversion/utilization systems has progressed through the normal stages of work plan and establishment of a technical literature file to enumeration of some process steps of specific concern. Such process steps are: (1) methanation, (2) product gas compression, (3) gas liquor separation, (4) phenol extraction, (5) gas liquor stripping, (6) sulfur recovery, and (7) storage of byproducts. Two cases were studied using low-sulfur Western coal as feed to gasification: (1) Rectisol I for acid gas treatment plus Stretford units for sulfur recovery, and (2) Rectisol II plus Stretford/Claus and tail gas treatment for sulfur recovery. Currently underway is the development of a sampling and analysis program suitable for obtaining IERL-RTP Level I assessment data for control technology evaluations. A Stretford process data report will be utilized to illustrate the factors connected with preparing such a program.

The contract for convertor output control technology development has been recently awarded. As the developer of a patented coal conversion process, this contractor has the background and experience to follow pathways for major as well as minor contaminants flowing through coal conversion systems. Projected contributions include a study of the deactivation effect of trace compounds in coal-derived gases in a shift convertor and participation in the establishment of an acid gas removal facility for pollutant studies under grant funding.

An award has been made for pretreatment and waste control technology development just prior to the submission of this paper, and the award for high-Btu gasification environmental assessment has also just been made.

Three institutions have been awarded major research grants. Research under the first award is aimed toward study of potential pollutant production from experimental synthetic fuels operations. Research will include screening of a large number of chemical species, determination of the effects of coal conversion reaction parameters on production of these species, and cataloging of kinetic data pertinent to the rates of formation of the significant pollutants. Construction of the reactor facility is almost complete, and preliminary system checkout has begun.

The second grant is for test and evaluation of a gas cleaning facility for gases from a bench reactor. Building modifications to the existing plant have been made, the overall system design is finalized, all major analytical equipment is on order, and fabrication is underway.

Thirdly, work under an IERL-RTP 5-year grant has been initiated (1) to assess biological and chemical treatment of wastewaters from fuel conversion, (2) to determine environmental impact and health effects of treated waters, and (3) to conduct bench-scale studies for developing water treatment design criteria. Studies are being initiated on selected "model" organic compounds and will then move to tests of composite waste streams.

General support to date has covered the preparation of the status report of Fuel Process Branch programs, preliminary compilation of the agenda for the September 1977 fuel conversion symposium, recommendations on data storage and retrieval requirements, and coordination and participation in the preparation of a control practice document for Lurgi coal gasification plants.

The efforts described above, although greatly expanded in magnitude from most previous programs under EPA fuel conversion technology, still reflect previous results and continuity of approach. More specific examples of this are present supporting programs which are essentially direct add-ons to the early accomplishments previously described. The objective of one study is to evaluate the technical, economic, and environmental intrusion characteristics of the integrated coal gasification/sulfur removal/combined cycle power systems for different gasifier types. Some of the work has been incorporated as a subtopic in the US/USSR working group in stationary source pollution.

Continued characterization of mineral matter in coal is being funded under a grant. A number of whole coals and wash residues have been analyzed to date. A complementary contract for the characterization of coal and coal residue has produced analyses of both whole and demineralized coal samples. An investigation of the effects of pyrolysis on the distribution of trace elements and collection of data on the solubilities and toxicities of potential pollutants contained in solid coal waste has begun.

More peripheral studies continue in the area of catalytic desulfurization, denitrogenation, and demetalization of liquid fuels. A low cost demetallization catalyst has been developed and promoter metal levels have been optimized. Experimental investigations of quinoline as a model nitrogen compound for denitrogenation under industrial reaction conditions have been initiated for applicability to synthetic liquids.

Research which preceded the ERDA interagency agreement, as described above, is concerned with water conservation and pollution control alternatives in coal gasification and liquefaction processes. Complete but not fully detailed designs of water treatment for conversion plants at conversion sites in North Dakota, New Mexico, and Wyoming have been made, and extended studies of water requirements are planned for 50 western plant site combinations.

Again, task orders under multioption contracts are providing the opportunity for additional support research; e.g., the continuation of the Multimedia Environmental Goals (MEG's) work whose initial efforts produced a recent draft report. The MEG's are an example of the environmental assessment methodologies being developed for fossil fuel energy processes.

These methodologies are needed on a near term basis to eliminate inefficiencies, inconsistencies, and proliferation of techniques for evaluating and comparing environmental effectiveness. Methodologies specifically or generally associated with synthetic fuels include (1) technology overview report outline, (2) process assessment criteria, (3) source unit operations, (4) control assay development concerned with environmental data acquisition, (5) compilation of regulations and standards, (6) multimedia environmental goals, (7) control approach category development, and (8) standards of practice manual outline for control technology for synthetic fuels. An Environmental Assessment Steering Committee is in operation to direct and support some of the above methodology tasks. Present levels of completion vary from approximately 10 to 90 percent on various tasks. The multimedia environmental goals development represents the most ambitious effort to date among these categories. Ambient control levels for insuring no ill effects on the health of man or hazards to the environment have been estimated for more than 200 compounds and elements. The suggested levels were derived from toxicity data, workroom standards, and elementary models for assimilation of substances by man, animals, and plants. A final report should be issued within the next month, and expansion to include an additional 400 compounds has begun.

Development of methodologies in support of synthetic fuels environmental control is closely associated with the current sampling and analytical methodologies being promulgated by the IERL-RTP under the designations Level I, Level II, and Level III. These analytical schemes will be incorporated in the sampling and analytical test plans for the coal conversion environmental contractors. In fact, coal conversion and advanced combustion will be included as important sample cases for the approach itself. An important facet of the approach is bioassay determination of toxicity level effects. This too has been discussed among the participants in the EPA synfuels program and will be incorporated into these sample efforts. The possible mutagenic or other health effects activities of some pollutants associated with synthetic fuels make this approach appropriate. Certainly the bioassay technique is an excellent tool for highlighting problem pollutants and eliminating others from the arena of concern.

All accomplishments in the above areas are being disseminated regularly through quarterly and annual reports, regular and frequent meetings of the primary contractors (where presentations by supporting researchers are also given), and by the encouragement of publications within the Agency and also in the open literature. The third symposium on the Environmental Aspects of Fuel Conversion Technology will be held in September of 1977.

The technical directive/level of effort type contract has allowed real-time direction enabling contractors to efficiently address the changing research needs and gain an early familiarization with the technology and procedures.

Future Plans Toward an Environmentally Sound Industry

The first steps beyond the present program will hopefully be the initiation of environmental testing at such facilities as the ERDA demonstration plants under interagency agreements. The expansion and solidification of EPA agreements with those engaged in energy research and also, very importantly, in toxicity and health effects testing, should be the best insurance for optimized environmental assessment and control technology development. Certainly agreements with the private sector, industrial organizations involved in coal conversion, must be encouraged as the industry develops. An example is the planned Commonwealth Edison plant which includes Lurgi gasification and combined cycle systems.

The EPA synthetic fuels program for environmental research and development has laid the foundations necessary to determine both the problems to be addressed and the areas where data acquisition can be most profitable. IERL-RTP is now moving into a phase which should include an order of magnitude increase in real data produced and in progress evidenced by major achievements and program milestones. The obvious result of the satisfactory continuation of this effort is the generation of information needed for evaluation and development of control technology and setting of standards and regulations. The intention is that complete background data for environmental evaluations and impact statement preparations will be ready when significant commercialized plants are ready for construction planning. Realization of this goal, the assurance of an environmentally sound synthetic fuels industry, is an important incentive to the development of this industry.

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POLLUTION ABATEMENT FOR WASTES-AS-FUEL PROCESSES

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INTRODUCTION

Under several legislative mandates, EPA is charged with developing processes to recover energy and materials from solid waste. EPA is also responsible for research into the characterization and control of the discharge of materials into the environment from conversion-to-energy processes.

Thermal processes for recovering energy from solid wastes are of three generic types --- mass burning, co-firing, and pyrolysis. Mass burners, or waterwall incinerators, produce steam through the direct combustion of solid waste. Mass burners have operated with varying degrees of success at such locations as Chicago, Saugus, Mass., and Nashville.

Co-firing produces steam and/or electricity through the combustion of processed solid waste and some fossil fuel, such as coal or fuel oil, in a fossil-fuel-fired boiler. Successful co-firing plants have operated at St. Louis, Ames, Iowa, and Columbus. Plants are planned or starting up in Chicago, Milwaukee, and several other cities.

Pyrolysis plants utilize some degree of destructive distillation to convert the waste material into a gaseous, liquid, or solid fuel product. Large-scale pyrolysis plants are in existence at San Diego, Baltimore, and South Charleston, West Virginia. Several other waste pyrolysis processes are being operated at generally lesser scales.

A mass and energy balance around any waste conversion operation will show that the input material is converted into end products such as fuel or ash, and into smaller quantities of by-product materials, or pollutants. These pollutants are rejected from the conversion operations and may be in the form of gaseous, liquid, or solid discharges to the environment. If these discharges are harmful to the environment they should be minimized and controlled.

AIR POLLUTANTS FROM EXISTING PLANTS

Due to the relative infancy of U. S. waste-to-energy technology, operating experience is not extensive. While a comprehensive EPA-sponsored characterization of pollutants from waste-to-energy processes is just getting underway (Ref.1), some air emissions data are available from operating plants.

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Table 1 is a compilation of flue gas constituents from the 720 TPD (ton per day) Nashville steam-generating waterwall incinerator (Refs. 2 & 3). Data on gaseous emissions were obtained from a series of six test runs while the particulate data was collected over three runs. Particulate data has been corrected to 12% CO_2 dilution. The inlet and outlet particulate data represent measurements into and out of the electrostatic precipitator, which is the primary air pollution control device employed at Nashville. The only current Federal standard for refuse incinerators is the particulate standard of 0.08 grains/dscf (0.18 grams/m^3).

TABLE 1. AIR EMISSIONS FROM NASHVILLE INCINERATORS (REFS. 2 & 3)

ITEM	UNITS	MIN.	MAX.	AVG.
Inlet				
Particulates	grains/dscf	0.941	1.677	1.200
Outlet				
Particulates	grains/dscf	0.018	0.028	0.024
NO_x	ppm	107	177	146
SO_2	ppm	22	51	38
CO	ppm	100	179	153
Chloride	ppm	63	177	110

Table 2 is a comparison of emissions from the combustion of high-sulfur coal alone and coal co-fired with refuse at the Columbus, Ohio, Municipal Light Plant (Ref. 4). The boiler is a 21 Mw stoker grate boiler. The refuse feed is a coarse shredded (4 X 4 in.) material. The tabulated refuse feed rates are 36 wt. % (20% fuel value) and 50 wt. % (28% fuel value). The Columbus plant has only a mechanical particulate control device. Only outlet concentrations of pollutants from this relatively inefficient device are recorded. Note that while some pollutants increase with refuse addition, SO_2 emissions decrease dramatically with increased refuse additions.

TABLE 2. AIR EMISSIONS FROM COLUMBUS COFIRING PLANT (REF. 4)

ITEM	UNITS	COAL ALONE	COAL + 20% REFUSE	COAL + 28% REFUSE
Particulates	grains/dscf	1.20[a]	0.45	N.D.[b]
NO_x	ppm	210	127	180
SO_2	ppm	2340	1190	400
CO	percent	0.1	0.022	0.20
CH_4	ppm	N.D.	2	19[c]
HCl	ppm	14	36	N.D.

N.D. = Not determined

(a) Cyclone separators defective
(b) 0.52 for 23% refuse
(c) 45 for 23% refuse

Table 3 is a comparison of air emissions for coal plus refuse vs. coal alone firing at the St. Louis Union Electric Meramec Plant (Ref. 5). The boiler is a 125 Mw pulverized coal tangentially-fired unit. The refuse firing rate for coal plus refuse derived duel (RDF) co-firing ranged from 5 to 20 percent by fuel value. As can be seen from the data in Table 3, the trend most evident is that there is no trend. In fact, scatter was prevalent in most all aspects of data acquisition at St. Louis. In general, emissions were independent of either refuse firing rate or even boiler steam load. The exception was chloride emissions, which appeared to increase about 30% for coal + RDF in comparison to concentrations noted for coal alone. The St. Louis plant has an electrostatic precipitator. However, testing showed that compliance with the New Source Performance Standards for particulate emissions (0.1 lb/10^6 Btu) would not be achieved above 100 Mw regardless of the fuel mix. Nonetheless, particulate emissions did generally increase when waste was being co-fired.

TABLE 3. RANGES OF AIR EMISSIONS FROM ST. LOUIS POWER PLANT (REF. 5)

ITEM	UNITS	COAL ALONE	COAL + RDF
Particulates (Outlet)	lb/10^6 Btu	0.06 - 0.25	0.02 - 0.50
CO	ppm	10 - 170	45 - 220
NO_x	lb/10^6 Btu	0.13 - 0.66	0.12 - 0.73
SO_x	lb/10^6 Btu	1.3 - 4.40	2.0 - 4.2

Operating experience at pyrolysis plants is far less extensive than it is at co-firing or waterwall incineration plants. Full-scale systems are often proprietary and are generally just now starting up operation. Comparisons between pyrolysis plants must be approached with caution since pyrolysis processes vary in concept from "pure" pyrolysis with no air addition to starved-air combustion operations. Table 4 is a listing of emission determinations from the City of Baltimore pyrolysis plant (Ref. 6). The pyrolysis plant is an 1000 TPD direct-fired rotating kiln starved-air combustion unit. Gas is produced in the kiln and combusted in a boiler to produce steam. The data presented in Table 4 are a compilation of emissions data before and after the scrubber located downstream of the boiler.

TABLE 4. RANGES OF AIR EMISSIONS FROM THE CITY OF BALTIMORE PYROLYSIS PLANT (REF. 6)

ITEM	UNITS	SCRUBBER INLET	SCRUBBER OUTLET
Particulates	grains/dscf	-	0.206 - 0.269
SO_2	ppm	120 - 171	7 - 15
NO_x	ppm	0.3 - 18.9	1.4 - 10.8
Cl^-	ppm	445 - 1250	32 - 140

WATER POLLUTANTS FROM EXISTING PLANTS

There does not exist a large base of data on waterborne pollutants discharged from waste-to-energy plants. Wastewater effluents from mass burning plants can be in the fore of ash quenchwater or, in some cases, scrubber water from particulate control devices. Liquid discharges from waste co-firing operations are limited to sluice waters from ash rejection and to scrubber waters from particulate removal or flue gas desulfurization processes. Pyrolysis liquid effluents can result from several sources: gas scrubbing, water and oil separation, char and ash sluicing, and discharge of intermediate process liquids.

While no data are available on the quality of the liquid effluent from the Saugus, Massachusetts mass burner, the average wastewater discharge from that plant is estimated to be 12 gallons per minute (Ref. 7). This is not a large flow rate but treatment of this effluent may nonetheless be necessary.

Sampling of sluicewater effluents from the St. Louis co-firing plant yielded no significant differences in potentially hazardous pollutants (such as cadmium, chromium, or mercury) between coal-only and co-firing operations. However, total dissolved solids (TDS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were higher for sluicewater from the coal + RDF operation (Ref. 5).

Wastewater effluents from pyrolysis processes may contain concentrated amounts of soluble organic and inorganic compounds. In addition, trace elements contained in RDF may be entrained in liquid discharges in higher concentrations than in the waste material itself. Union Carbide, which markets the Purox waste pyrolysis system, recommends treatment of liquid discharges from the Purox process with their Unox water treatment system.

POTENTIAL POLLUTION PROBLEMS FROM WASTE-AS-FUEL PROCESSES

The significant numbers to look at in evaluating pollution aspects of waste-to-energy processing are the differences in pollutant emissions between waste-to-energy operations and (1) competing waste disposal methods and (2) production of energy from competing fuels. Waste disposal through energy conversion is, first and foremost, a waste disposal operation; disposal via energy recovery must dispose of the waste material in a manner not detrimental to the environment.

The sanitary landfill remains the primary mode of disposal of solid waste. Generally, given adequate available land area, landfilling is the most economical waste disposal method. In many large metropolitan areas, such space is often not available in close proximity to the sources of waste generation. Primary sources of pollution in landfill operations are liquid effluents in the form of leachate and gaseous emissions from the decomposition of organic materials. Secondary pollutants are emitted from transport vehicles negotiating haul distances to remote land disposal sites. Most often, the decision to seek alternatives to land disposal is a function of economic, political, and social concerns.

For waste-to-energy installations, the data on pollutant emissions are sparse and inconclusive. However, some trends are evident. In co-firing operations, particulate emissions exhibit a slight upward tendency (compared to conventional coal burning). However, the data also show that fossil fuel-fired facilities have yet to completely solve their own particulate problems.

Refuse is a low sulfur fuel. While some data, notably the St. Louis data, do not indicate a definite reduction in sulfur emissions, there is substantial operating experience to support the contention that refuse firing should result in decreased sulfur oxide emissions. Oxides of nitrogen and carbon monoxide emissions are also not major concerns from waste-to-energy facilities.

Pollution control problems from waste-to-energy processes are not so much a function of quantities of emissions as a function of the characteristics of the pollutant emissions. Several potential areas of concern can be identified.

The fly ash from waterwall incinerators is extremely fine in comparison with that emanating from refractory wall incineration (Ref. 8). Studies from Harrisburg and Nashville indicate that 21 to 30 percent by weight of the fly ash emitted from these waterwall plants is less than 1 micron in diameter. For refractory-wall incinerators, perhaps only 10% is less than 1 micron (Ref. 8).

Figure 1 illustrates observed deterioration of electrostatic precipitator (ESP) performance with increasing RDF and boiler load at the St. Louis plant (Ref. 5). As can be seen from Figure 1, ESP efficiency undergoes a fairly substantial reduction at higher boiler loadings when refuse is being fired in the boiler.

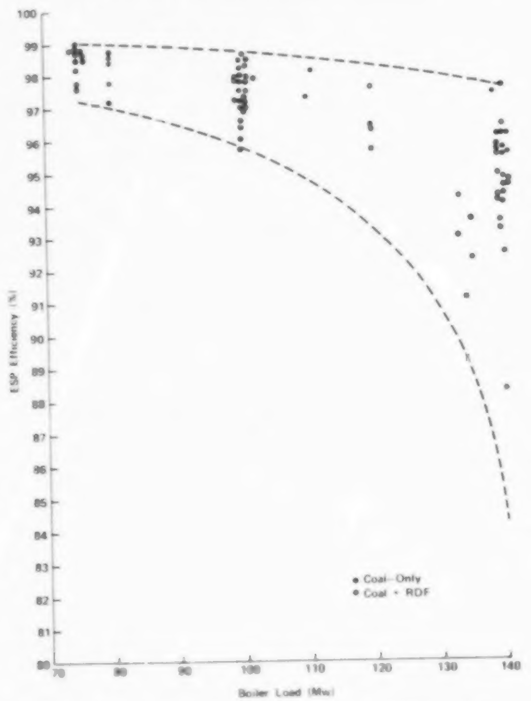

Figure 1. ESP efficiency as a function of boiler load.

Data from St. Louis also reveal an average increase of 30 percent in chloride emissions when refuse is burned over such emissions when coal alone is fired (Ref. 5). Chloride, in the form of HCl, can be corrosive to boiler components in addition to representing an environmental concern.

Table 5 is a comparison between coal and coal + RDF of some trace element pollutant concentrations at St. Louis (Ref. 5). Potentially hazardous trace elements are present in coal as well as in solid waste. At present, no standards exist for metallic trace element emissions and such pollutants as possibly carcinogenic polycyclic organic materials (POM's). However, as more becomes known about the effects of emission of these trace materials, impetus for standard-setting and control will become more pronounced.

TABLE 5. CONCENTRATIONS OF SPECIFIC POLLUTANTS AT ST. LOUIS (REF. 5)

	AVERAGE CONCENTRATION IN COAL AND RDF (μg/g)		AVERAGE CONCENTRATION IN EMITTED FLY ASH PARTICLES (μg/g)	
Element	Coal	RDF	Coal Only	Coal + <20% RDF
Sb	<1	<1	1.46	10.0
As	<1	<3	162	36.0
Be	<1.3	<1.2	10.3	12.7
Cd	0.28	13.8	29.6	25
Cr	32	283	624	293
Pb	64	466	583	982
Hg	<0.3	4.0	<7.9	7.5

Pyrolysis results in the concentration of trace organics and inorganics in the gaseous, liquid or solid products. The forms of the trace materials can be substantially different from the forms of these materials produced under the oxidizing conditions of combustion.

POLLUTION CONTROL TECHNOLOGIES AT EXISTING PLANTS

Pollution control equipment in use at existing plants vary in effectiveness. Several types of air pollution control devices have been employed on waste combustion, co-firing, and pyrolysis processes. There is very little operational experience relating to wastewater and residue pollution control. Air pollution control has, to this point, received the most attention at waste-to-fuel plants and particulate control has been the subject of most interest.

Table 6 is a description of particulate removal efficiencies for several generic types of air pollution control devices. Most electrostatic precipitators (ESP's) sold today are designed for 98 to 99.5% collection efficiency (Ref. 9).

TABLE 6. AIR POLLUTION CONTROL EQUIPMENT COLLECTION EFFICIENCIES (REF. 9)

EQUIPMENT TYPE	TOTAL EFFICIENCY RANGES (Total Wt. Basis, %'s)
Electrostatic Precipitators	80 to 99.5+
Fabric Filters	95 to 99.9
Mechanical Collectors	50 to 95
Wet Scrubbers	75 to 99+

Early-generation European waterwall incinerators employed mechanical collectors or low-energy impingement wet scrubbers. Later-generation waterwalls use high-energy venturi scrubbers and electrostatic precipitators to control particulate emissions. The Nashville plant has utilized both wet scrubbers and an electrostatic precipitator. The Saugus steam-generating plant uses two electrostatic precipitators. Most new plants employ or plan to use the more efficient ESP's.

The trend at fossil-fueled power plants has likewise been toward more efficient particulate collection devices. Older power plants operated with mechanical collectors. Newer plants generally employ ESP's. In the future, high-energy scrubbers may be installed for the purpose of combined flue gas desulfurization and particulate collection. The need for more efficient particulate collection, and also for effective gaseous emission control, has resulted in experimental development of hybrid systems and completely new equipment such as "wet" ESP's.

Fuel-gas producing pyrolysis operations generally require some cleaning of the fuel gas at the point of gas production. Gas produced from the Purox system is scrubbed of particulates and CO_2. Gas produced at the Baltimore pyrolysis plant is combusted on-site and spent combustion gases are subjected to wet scrubbing.

In summary, technology for control of air pollutants from energy-producing plants is in a state of flux. Fossil-fuel-fired power plants face a formidable task in meeting New Source Performance Standards for particulate and gaseous emission control. The ability of waste-to-energy operations to conform to environmental standards will, to a large extent, depend on the improvement of existing technologies and the development of new techniques to control environmental discharges from both fossil-fuel-fired plants and waste-to-energy plants.

EPA's APPROACH TO POLLUTION ABATEMENT FOR WASTES-AS-FUEL PROCESSES

EPA's approach to control of pollutants emanating from wastes-to-energy processes consists of parallel efforts in three areas:

1. Pollutant Identification and Characterization
2. Air Pollution Control Technology Development
3. Water Pollution Control Technology Development

Each program consists of extramural research activities administered and technically directed by OEMI's Fuels Technology Branch (FTB) of IERL-Cincinnati. Specific programs are synopsized below.

Pollutant Identification and Characterization

Pollutant characterization is an ongoing component of the FTB's Wastes-as-Fuel program. Assessment of the environmental characteristics of waste-to-energy processing is routinely included in research and development projects supported by the Branch. Such projects include experimental testing of combustion, co-firing, and pyrolytic approaches with a variety of wastes under varying conditions.

In addition, the FTB has recently initiated a comprehensive contract effort with the Midwest Research Institute (MRI) to assess the environmental impact of waste-to-energy processes (Ref. 1). Under the terms of the contract, MRI will perform on-site measurements of discharges to the air, water, and land from operating waste-to-energy plants. The contractor will assess the impacts of these discharges on the environment and identify specific pollutants requiring control.

As part of the assessment effort, MRI will assess waste and pollutant sampling methods. The sampling methods recommended by MRI will, quite likely, serve as standardized sampling techniques for all waste-to-energy plants.

MRI will perform pollutant characterization for all of the generic types of waste-to-energy processes: waterwall incineration, co-firing, pyrolytic conversion and biological conversion. Promising developing technologies will also be evaluated.

In addition to on-site pollutant characterization, MRI will also perform pollution control trade-off studies. These studies will serve to establish cost and process configurations which provide systems for maximum energy recovery with minimal environmental impact and cost.

While the MRI study will concentrate on discharges of regulated criteria pollutants, potentially hazardous trace pollutants will also be monitored and assessed. In this manner, specific problem areas, not currently impacted by regulations, can be anticipated.

Air Pollution Control Technology Development

In early 1977, EPA entered into a contract with PEDCO Environmental, to conduct research in the area of air pollution control for waste-to-energy processes (Ref. 10). The goal of this effort is to develop environmentally acceptable air pollution control processes that can be used in conjunction with waste-to-energy processes. The method to be employed in the PEDCO study will be a five-phased approach ranging from data collection to field-testing of pilot-scale air pollution control systems at operating waste-to-energy plants.

The first phase will consist of collection of data on known and potential air pollutants from waste-to-energy processes. Data input to this phase will come from operating experience at existing plants and from the previously described MRI environmental assessment study.

In the second phase, the contractor will assess the ability of existing air pollution control technologies to control emissions from waste-to-energy facilities. Operating experience and the contractor's knowledge of air pollution and its control will be brought to bear in this phase of the effort.

Upon completion of the first two phases, the contractor and EPA will be in a better position to determine the need for development of air pollution control technologies specific to waste-as-fuel processes. If a determination is made that existing pollution control technologies are not adequate, PEDCO will design pilot-scale air pollution control systems to be installed at operating waste-to-energy plants. Of course, if it is found that conventional air pollution control technologies are adequate, no further development will be pursued.

Phases four and five will consist of construction and testing of the pilot-scale air pollution control systems at operating plants. It is expected that several sites will be visited by the air pollution control pilot plants.

Under the PEDCO contract, development will simulate two situations:

1. Development of control systems to be retrofitted into existing plants
2. Development of control systems to be installed at new plants.

Water Pollution Control Technology Development

In an effort parallel to the air pollution control study, EPA will soon award a contract to develop water pollution control technologies for waste-to-energy processes (Ref. 11). The approach will consist of a similar five-phased study culminating in pilot plant testing of water pollution control technologies developed through the course of the contract endeavor.

CONCLUSION

Conversion of waste-to-energy is a developing industry in the U. S. With each succeeding generation of waste-to-energy processes, more is learned about the environmental impact of such processing. This paper outlines what is known today about the environmental benefits of waste-as-fuel systems (e.g. the reduction in SO_2 emissions and the near elimination of landfill gas and leachate problems) and discusses some of pollution problems associated with these technologies. It also describes EPA's R&D program aimed at more fully characterizing these pollution problems and their efforts at developing control technologies to solve them.

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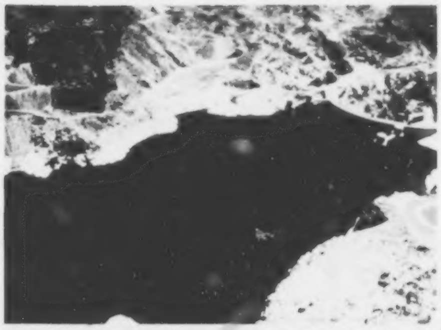

CHAPTER 3

utility and industrial power

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UTILITY AND INDUSTRIAL POWER

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INTRODUCTION

I welcome the opportunity to summarize the utility and industrial power portion of the energy/environmental program. Since this subject encompasses several important control technologies and represents a major fraction of the total interagency program, with annual funding at about $30 million, my talk will be somewhat long.

Figure 1.
Utility and industrial power

- FLUE GAS DESULFURIZATION (FGD)
  - NON-REGENERABLE (THROWAWAY)
  - REGENERABLE (SALEABLE PRODUCT)
- NITROGEN OXIDE CONTROL
  - COMBUSTION MODIFICATION
  - FLUE GAS CLEANING (FGC)
- PARTICULATE CONTROL
- WASTE AND WATER
  - EFFLUENT SOLID WASTES CHARACTERIZATION/CONTROL
  - COOLING TOWER TECHNOLOGY
  - WASTE HEAT UTILIZATION

Let me begin by mentioning the subject areas covered (Figure 1) and the authors of the specific papers who act as panelists.

Utility and Industrial Power encompasses, first, flue gas desulfurization technology, both nonregenerable and regenerable processes. Our panelists in this area are Michael Maxwell and Richard Stern of our Industrial Environmental Research Laboratory at Research Triangle Park (IERL/RTP), North Carolina, and co-author Gerald McGlamery, Chemical Development, Tennessee Valley Authority (TVA). Panelist George Blair Martin (IERL/RTP) will discuss nitrogen oxide control. Dale Harmon (IERL/RTP) will then discuss particulate control, and Julian Jones (IERL/RTP) and Dr. Hollis Flora (TVA) will discuss the cleanup position of our waste and water program.

CLEAN AIR ACT AMENDMENTS

The Clean Air Act Amendments of 1970 are the major driving force for control of air pollution from both new and existing combustion sources. The Act has a statutory requirement to achieve acceptable ambient air quality for the so-called criteria pollutants (Figure 2). Among these pollutants are sulfur dioxide and total suspended particulates, which are essentially stationary source pollutants, and nitrogen oxides, which are generated by both stationary and mobile sources in roughly equal quantities. In addition, the Clean Air Act calls for the promulgation of New Source Performance Standards (NSPS) for a variety of polluting industries, including coal-fired steam generators. Presently, standards are on the books for control of sulfur dioxide, total suspended particulates, and nitrogen oxides from coal-fired, oil-fired, and gas-fired steam generators. The present NSPS for coal units, as well as for typical uncontrolled emissions, are included in Figure 2. The present NSPS for coal-fired steam generators calls for approximately 70-80 percent control of sulfur oxide, approximately 98 percent control of high particulates, and roughly a moderate 30 percent control of nitrogen dioxide.

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Figure 2.
Clean Air Act–driving force for flue gas cleaning

- STATUTORY REQUIREMENT TO ACHIEVE ACCEPTABLE AMBIENT AIR QUALITY FOR:

SO_2
TSP
NO_x
HYDROCARBONS
CARBON MONOXIDE
PHOTOCHEMICAL OXIDANTS

↕ STATIONARY SOURCES (SO_2, TSP, NO_x)
↕ MOBILE SOURCES (NO_x, HYDROCARBONS, CARBON MONOXIDE, PHOTOCHEMICAL OXIDANTS)

- STATUTORY REQUIREMENT TO MEET NSPS FOR COAL-FIRED STEAM GENERATORS

	STANDARD	UNCONTROLLED
SO_2:	1.2 LB/10^6 BTU	5 LB/10^6 BTU
TSP:	0.1 LB/10^6 BTU	6-10 LB/10^6 BTU
NO_2:	0.7 LB/10^6 BTU	1 LB/10^6 BTU

BEST-AVAILABLE CONTROL TECHNOLOGY

I must point out that certain changes may occur, both in terms of the Clean Air Act and some revised standards under the present Act, that could have important impact on control technology requirements for fossil-fuel combustion units. Figure 3 lists three of these possible changes. First, the House and Senate have recently passed legislation, which has gone to joint committee, calling for a best-available control technology (BACT) approach for new coal-fired power plants, insofar as sulfur dioxide and particulate pollution are concerned. Although the implementation details of BACT have not been worked out and the final version of the Act has not yet passed both Houses, the change would require BACT for all new sources on both low- and high-sulfur coal applications, eliminating the low-sulfur control option to meet sulfur oxide standards.

Figure 3.
Important ACT/STD possible changes

- BACT FOR COAL-FIRED POWER PLANTS
- MORE STRINGENT NSPS FOR COAL-FIRED POWER PLANTS: SO_x, NO_x, TSP
- NSPS FOR INDUSTRIAL BOILERS (< 25 MWE): NO_x, TSP

The second change might involve more stringent NSPS than the existing standards for coal-fired power plants. Under consideration are revised standards which could lead to more stringent control for sulfur dioxide, nitrogen oxides, and total suspended particulates (TSP).

Third, for industrial boilers the Agency is considering NSPS of less than about 25 MWe (equivalent) for nitrogen oxide, TSP and possibly sulfur oxides.

PRESIDENT'S ENERGY MESSAGE

The President's recent energy message highlights the need for effective control technology for coal combustors. The message calls for expansion of the annual coal production rate from the 700 million tons presently produced to over 1 billion tons by 1985. His policy also calls for massive conversion of existing utility and industrial power facilities from oil and gas to coal, and for essentially no new oil or gas industrial or utility boilers. Future options for these applications would generally be coal, nuclear, or one of the emerging energy technologies. Although the conservation aspects of the President's plan and the assumption of strict environmental control minimize environmental degradation, total emissions of nitrogen oxides and sulfur oxides are projected to rise above present levels by 1985. The President's energy message also calls for accelerated research, development, and demonstration for the so-called clean coal technologies: coal cleaning, flue gas desulfurization, particulate control, fluidized-bed combustion, gasification, liquefaction, and coal mining. In fact, we in the energy/environmental program are planning, with the Office of Management and Budget an accelerated program for certain coal combustion control technologies. We hope to get a relatively large funding spike in fiscal year 1978 to accelerate our present development/demonstration efforts in the technology areas of flue gas desulfurization, nitrogen oxide control, particulate control, coal cleaning, and coal processing.

We have then the possibility of more stringent emission regulations because of possible Clean Air Act revisions and the upgrading of present NSPS, superimposed on an energy plan for increased burning of coal. Clearly, effective and low-cost control technology for utility and industrial sources is needed in the near term.

Figure 4 summarizes the critical problems associated with utility and industrial conventional combustion. This figure shows briefly the primary problems associated with such combustion, whether or not there are existing standards, major near-term control technologies available, the present status of these technologies, the secondary residuals produced by these technologies, and finally, the control technology R&D needed to resolve some of the remaining problems. The primary problems associated with industrial conventional combustion include the primary air pollutants—sulfur oxide, nitrogen oxide, particulates, and potentially hazardous materials—as well as some of the waste and water effluents associated with the control technology and the power plant itself.

Figure 4.

Summary of critical problems—utility and industrial conventional combustion

DESCRIPTION OF PROBLEM	STANDARD PRESENTLY ESTABLISHED	TYPE OF FGC CONTROL TECHNOLOGY	PRESENT STATUS	SECONDARY RESIDUALS	NEEDED CONTROL TECHNOLOGY R&D (INCLUDING ASSESSMENTS)
PRIMARY POLLUTANTS SO_2	YES NSPS AND AAQS	COAL CLEANING	1ST GENERATION DEMO PLANNED	HIGH S REFUSE	A) ELIMINATION OF SECONDARY POLLUTANTS B) DEMONSTRATE PRACTICABILITY C) BROADEN APPLICABILITY
		FGD	1ST GENERATION IN FULL SCALE DEMO 2ND GENERATION IN BENCH AND/OR PILOT SCALE	SLUDGE, PURGE STREAMS	A) ELIMINATION OF SECONDARY POLLUTANTS B) IMPROVE RELIABILITY C) BROADEN APPLICABILITY D) IMPROVE ENERGY EFFICIENCY
NO_x	YES NSPS AND AAQS	COMBUSTION MODIFICATION	COMMERCIAL FOR SOME NEW UNITS	POSSIBLY INCREASED PARTIC. AND CO	A) BROADEN SOURCE APPLICABILITY B) IMPROVE ENERGY EFFICIENCY C) IMPROVE NO_x CONTROL EFFICIENCY D) MINIMIZE IMPACT OF RESIDUAL POLLUTION
		FLUE GAS TREATMENT	PILOT SCALE AND DEMO IN JAPAN	VARIES WITH PROCESS	
PARTICULATES	YES NSPS AND AAQS	ELECTROSTATIC PRECIPITATORS	COMMERCIAL	FLY ASH	A) IMPROVE COST EFFECTIVE FINE PARTICULATE CONTROL B) BROADEN APPLICABILITY C) DEVELOP NOVEL DEVICES WITH IMPROVED CAPABILITY
		BAG HOUSES	1ST GENERATION DEMO		
		WET SCRUBBERS	1ST GEN. COMMERCIAL 2ND GEN. FULL SCALE DEMO		
		NOVEL DEVICES	BENCH OR PILOT SCALE		
POTENTIALLY HAZARDOUS MATERIALS	NO	UNDEFINED	UNDEFINED	UNDEFINED	PROBLEM REQUIRES DEFINITION

With this background information, I will now discuss some of the highlights of our ongoing reasearch, development, and demonstration program.

FLUE GAS DESULFURIZATION

I, first, would like to discuss our flue gas desulfurization (FGD) program (Figure 5). The systems produce either throwaway (disposable) or saleable products. In the throwaway FGD area, one of the most important single projects is the Shawnee lime/limestone prototype program which we have conducted with the aim of improving lime and limestone scrubbing processes. Such processes have been selected for many utility applications; approximately 40,000 MWe or $3 billion worth of these systems are presently in operation or on order at this time.

Figure 5.

EPA-sponsored stack gas desulfurization demonstration systems

EPA-SPONSORED PROCESS (BY PRODUCT)	PARTICIPATING UTILITY	PROCESS DEVELOPER	LOCATION	UNIT SIZE AND TYPE	EXPECTED START-UP
NON-REGENERABLE					
LIMESTONE SLURRY SCRUBBING (SLUDGE)	TVA	BECHTEL AND OTHERS	SHAWNEE UNIT 10 PADUCAH, KY	10 MW COAL	UNDER WAY
LIME SLURRY SCRUBBING (SLUDGE)	TVA	CHEMICO, BECHTEL, AND OTHERS	SHAWNEE UNIT 10 PADUCAH, KY	10 MW COAL	UNDER WAY
DOUBLE ALKALI SCRUBBING	LOUISVILLE G&E	CEA/ADL	CANE RUN 6	270 MW	EARLY - 1979
REGENERABLE					
MAGNESIA SLURRY SCRUBBING - REGENERATION (98% SULFURIC ACID)	BOSTON EDISON	CHEMICO-BASIC	MYSTIC STATION 6 BOSTON, MASS	150 MW OIL	COMPLETED
SODIUM SCRUBBING REGENERATION (SULFUR)	NORTHERN INDIANA PUBLIC SERVICE CO	DAVY POWERGAS ALLIED CHEMICAL	D. H. MITCHELL STATION 11 GARY, IND	115 MW COAL	LATE - 1975
AQUEOUS CARBONATE	NIAGARA MOHAWK	ATOMICS INTERNATIONAL	HUNTLEY STATION	100 M COAL	EARLY - 1979

SCRUBBING PROCESSES

The Shawnee program has been a cooperative effort of the EPA, the TVA, and the Bechtel Corporation. Two 10 MWe scrubbers have been operated since 1972, and a 0.1 MWe pilot scrubber has been operated in support of the two larger facilities since about 1973. This program has demonstrated long-term reliable operation of both lime and limestone processes. The particularly troublesome mist-eliminator plugging problem has been solved by a combination of careful operating conditions and carefully selected mist-eliminator washing configurations. During the course of our program, we discovered the potential of unsaturated operation to avoid the gypsum scaling that had plagued earlier commercial systems. This approach involves selecting operating parameters so that scrubbing liquors never get saturated or super-saturated in calcium sulfate, thereby avoiding potential scaling problems. Also, during the course of the program, we learned how to achieve high-alkali utilizations. For example, limestone utilizations of over 90 percent have been achieved. This leads to lower alkali requirements and lower sludge production rates, both of which yield lower operating costs. We have also achieved high sulfur oxide removal efficiencies. Typically, efficiencies for both lime and limestone systems in excess of 95 percent can be achieved without an excessive economic penalty. One of our most recent findings is that minor process modification can allow for sludge oxidation to gypsum, producing a material capable of 90 percent dewatering by filtration. Since last year, we have developed a design/cost computer model which acts as a data base for all the information the EPA, TVA, and Bechtel team knows about lime/limestone scrubbing and allows a given utility or other FGD user to input application parameters and output a conceptual design along with some good cost estimates.

LIME SCRUBBING PROCESSES

The Louisville Gas and Electric (LG&E) Lime Study Program has generated useful information since our last conference. The purpose of this program is to study unsaturated operation (which had been occurring at Louisville at Paddy's Run No. 6 unit) and to look at some alternative sludge disposal techniques. Results to date indicate that carbide lime, which is the normal Paddy's Run reactant, has an oxidation inhibitor that lowers the oxidation rate, with subsequent lower saturation and scaling potential. These tests are being continued in an attempt to understand and apply this mechanism to other systems.

Also in the lime scrubbing area, the TVA has operated a high-velocity scrubber at the Colbert Power Station. This 1 MWe-size scrubber has demonstrated reliable operation using lime as the reactant. Mist eliminator problems which had been troublesome in the past have been resolved. High-velocity scrubbing has the advantage of a smaller scrubbing system with corresponding lower costs relative to existing scrubber technology.

We have been working with the Air Force in operating and testing a lime scrubber system on a 21 MWe coal-fired industrial boiler at the Rickenbacker Air Force Base. This unit started up in March 1976, and although there were some boiler control and fan problems, the efficiency and reliability of the scrubber have been good. Also, the economics of such scrubbing systems on industrial boilers of this size does not appear prohibitive.

DOUBLE ALKALI SCRUBBING PROCESSES

As an alternative to lime and limestone nonregenerable FGD systems, our program has been actively developing the double alkali scrubbing process. Although the double alkali system has basically the same chemicals entering and leaving the process, it has several potential advantages over lime/limestone scrubbing processes, such as less energy consumption, higher sulfur oxide removal efficiency, lower maintenance, and lower capital and operating costs. The EPA program has actively developed double alkali technology at the bench and pilot levels. We have worked with Southern Services at the 20 MWe electric prototype system, and most recently we have worked with the General Motors Company for applying a double alkali process variation to one of the GM industrial boilers. In the past, this double alkali scrubber had generally good operability on the 32 MWe industrial boiler, although some problems were encountered. It should be noted that for the previously mentioned Rickenbacker lime unit, the approximate capital costs of $100 per KWe on this size of industrial boiler do not appear excessive.

Recently, the EPA announced plans to demonstrate the double alkali process on a high-sulfur coal utility boiler. The Louisville Gas and Electric Company and its 270 MWe electric Cane Run No. 6 unit were selected for this demonstration. Combustion Equipment Associated/Arthur D. Little comprise the process supplier team. It is noteworthy that the cost of this unit—and these costs are fairly firm—is estimated to be only $55 per KWe capital costs; and $2.5-2.9 mills per KWe hour of total annual revenue requirements. Also, only 1.1 percent of the power plant's energy output is required to run the fans and pumps for this process. This is roughly one-third to one-half the energy requirement of similar lime or limestone systems.

REGENERABLE PRODUCT FGD SYSTEMS

As an alternative to lime and limestone systems with their inherent sludge production, we have been developing and demonstrating regenerable (or saleable) product FGD systems. For example, we have demonstrated the promising magnesium oxide scrubbing process at Boston Edison's Mystic Station. This scrubbing facility was tested on a 155 MWe oil-fired boiler and produced saleable sulfuric acid. The test program was initiated in April 1972 and completed in June 1974. Although many early problems were identified, particularly those associated with the various solid handling operations, operability improved substantially toward the end of the test program. Unfortunately no meaningful demonstration of this process has been performed on the critical coal-fired combustion units.

Since the last conference, we have started up our Wellman Lord demonstration test program. Wellman Lord technology involves scrubbing with a soluble reactant followed by thermal regeneration, producing concentrated sulfur dioxide which can yield either sulfuric acid or elemental sulfur. This process has been successfully demonstrated in Japan on a variety of oil-fired facilities. The EPA demonstration program is on a 115 MWe electric coal-fired facility at the Northern Indiana Public Service Company and produces elemental sulfur. The facility started up in April 1976 but, due to a boiler explosion, is now in a restart-up mode. Hopefully, some definitive findings on this process will be available at our next conference.

We have selected Atomic International's Aqueous Carbonate Process for the regenerable FGD process demonstration mentioned at last year's conference. The process will be demonstrated at Niagara Mohawk's Huntley Station and we are hoping that the system will start up in early 1979. It offers cost and other advantages over alternative regenerable processes, but because of the relatively small scale of previous test experience, it must be considered a relatively high risk venture.

I should also mention that since our last conference we have terminated our Catalytic Oxidation FGD demonstration program. This process, which produces a dilute sulfuric acid for sale, had been plagued with operating problems, and the utility had decided to burn low-sulfur coal in our test boiler. Therefore, it was decided that it would not be appropriate to invest additional monies toward demonstration of this process and our program was terminated. The EPA is also working with the U.S. Bureau of Mines in applying the regenerable Citrate Process to a large industrial facility. Figure 5 summarizes only the major EPA-sponsored demonstration programs for both throwaway and saleable product FGD processes.

BY-PRODUCT MARKETABILITY STUDIES

In addition to our demonstration activities, TVA working for the EPA has conducted a series of very relevant by-product marketability studies which help put the sulfur, sulfur acid, and other sulfur by-product sale situations in perspective. Also, studies have been made to evaluate alternatives to scarce natural gas as reductant materials to produce elemental sulfur from the concentrated sulfur dioxide associated with many regenerable FGD processes.

OTHER FGD PROGRAMS

Let me conclude my discussion of our FGD program by briefly mentioning three other important programs. First, the TVA has prepared a number of FGD process economic studies which in my mind are the most reliable cost estimates for both throwaway and saleable FGD processes. Secondly, the EPA in conjunction with the Council on Environmental Quality is working on a study comparing scrubber availability with that of other power plant components. Preliminarily, it appears that there is insufficient information to do a statistically convincing comparative study. However, several major power plant components appear to have reliabilities lower than some of the more recent FGD systems.

Finally, I would like to mention the very active technology transfer program in the FGD area. Some of the outputs of this program include the PEDCo Status Report (published every other month) which summarizes what is going on in the scrubber field, in terms of both operating and planned systems. Also, we now publish quarterly RD&D status reports summarizing the results of our ongoing research program. We are preparing lime and limestone data books and cost and reliability handbooks which provide potential users important information on commercial or noncommercial technologies.

NITROGEN OXIDE CONTROL

Now, let us discuss our NO_x control program. A little background might be in order. Figure 6 outlines some relevant history. In 1972 an unreliability problem was discovered in the ambient air quality measurement technique for NO_2.

Figure 6.
NO_x control requirements

- UNRELIABILITY OF NO_2 MEAS. METHOD DISCOVERED IN 1972, LED TO 43 OF 47 AQCRS RECLASSIFIED FROM HIGH TO LOW POLLUTION; ONLY FOUR PROBLEM AREAS
- HOWEVER, NO MAJOR PROGRESS MADE IN OBTAINING AAQS FOR NO_2; PROBLEM GROWING
- PRESENT CONTROL STRATEGY: MODERATE AUTO CONTROL
  NSPS FOR UTILITIES
  NSPS FOR NITRIC ACID PLANTS
  SEEMS INSUFFICIENT TO MEET AAQS
- BY 1985 16 MILLION TONS NO_x/YR FROM INDUSTRY AND UTILITIES; INCREASE OF 25% OVER PRESENT LEVELS
- IT APPEARS CONTROL OF STATIONARY SOURCES BEYOND PRESENT LEVELS WILL BE NECESSARY
- MAJOR TECHNIQUES FOR NO_x CONTROL
  COMBUSTION MODIFICATION
  FLUE GAS CLEANING
  FLUIDIZED BED COMBUSTION

Prior to discovery of the problem, it was believed that 47 of the total 247 Air Quality Control Regions (AQCRs) for the country had an NO_2 ambient air problem. We have found that, due to an inherent measurement error, ambient levels of NO_2 were measured too high. Using more accurate techniques, we found that only four AQCRs really seemed to have an NO_2 problem.

However, since 1972, there has been little progress in NO_2 control from either stationary or mobile sources. As a result, new AQCRs that exceed the NO_2 standard are being found, and the trend seems to be toward further NO_2 ambient quality problems. Therefore, our present NO_2 control strategy, which includes control of both mobile (automobile) and stationary sources, does not appear very effective.

I should point out that almost one-half of the NO_x emissions are from mobile sources; a little more than one-half are associated with stationary sources. So both are of interest if we are to achieve NO_x air quality goals.

We have set interim standards for automobiles. They are not very stringent standards, in fact, substantially less stringent than the Clean Air Act goal. Due to economic, technological, and political considerations, relatively moderate NO_x emission standards will prevail for autos in the near term.

Also, the NSPS philosophy is based on best-available control technology. Since technology for stringent control is not available, the NSPS for utility boilers is not very restrictive and requires, as I indicated earlier, only 30 or 35 percent control. There is also an NSPS for nitric acid plants, which contribute significantly to the NO_x problem.

So, our present strategy does not seem to be sufficient to get these AQCRs back into line or, for that matter, to turn around the trend toward additional AQCRs getting out of standard. Therefore, additional control of stationary sources beyond the present level may be necessary. Of course the NO_x problem is more complex than just NO_2; NO_x is a major precursor for photochemical oxidant and nitrate production.

NO_x CONTROL TECHNIQUES

There are three major categories of NO_x control for stationary sources. The only near-term technology is combustion modification, on which the present EPA program is primarily focusing. This technology is the basis for the present NSPS on large fossil fuel generators. Flue gas cleaning is the second technology. It is similar to flue gas desulfurization and should probably be called flue gas denitrification. We have several embryonic programs in that area which I will describe briefly. And finally, a very promising technology for NO_x control is fluidized bed combustion, which Mr. Singer discussed earlier. It is probably 10 years away from making a commercial impact but is a very promising technology nevertheless.

The combustion modification program aims to develop technology capable of controlling emissions from the two major stationary sources of NO_x; namely, thermal NO_x and fuel NO_x (Figure 7). We hope to control thermal NO_x by lowering the combustion temperature, since lower temperatures retard NO_x formulation; i.e., higher temperatures favor the oxidation of nitrogen. And one can control fuel NO_x problems by lowering oxygen concentration. The control approaches to both thermal and fuel NO_x are generally common, with the exception of fluidized bed combustion, which is oriented primarily toward minimizing thermal NO_x.

Figure 7.
NO_x combustion modification

- INVOLVES CONTROL OF THERMAL NO_x BY LOWERING COMBUSTION TEMP BY:
  - STAGED COMBUSTION
  - LOW EXCESS AIR
  - FLUE GAS RECIRCULATION
  - BURNER DESIGN MODS
- INVOLVES CONTROL OF FUEL NO_x BY LOWERING OXYGEN CONC. IN COMBUSTION ZONE BY:
  - LOW EXCESS AIR
  - STAGED COMBUSTION
  - BURNER DESIGN MODS
- TECHNIQUES INVOLVE TRADE-OFFS SINCE ADVERSE EFFECTS INCLUDE:
  - INCREASES OF OTHER POLLUTANTS
  - LOWERING THERMAL EFFICIENCY
  - OPERATING PROBLEMS

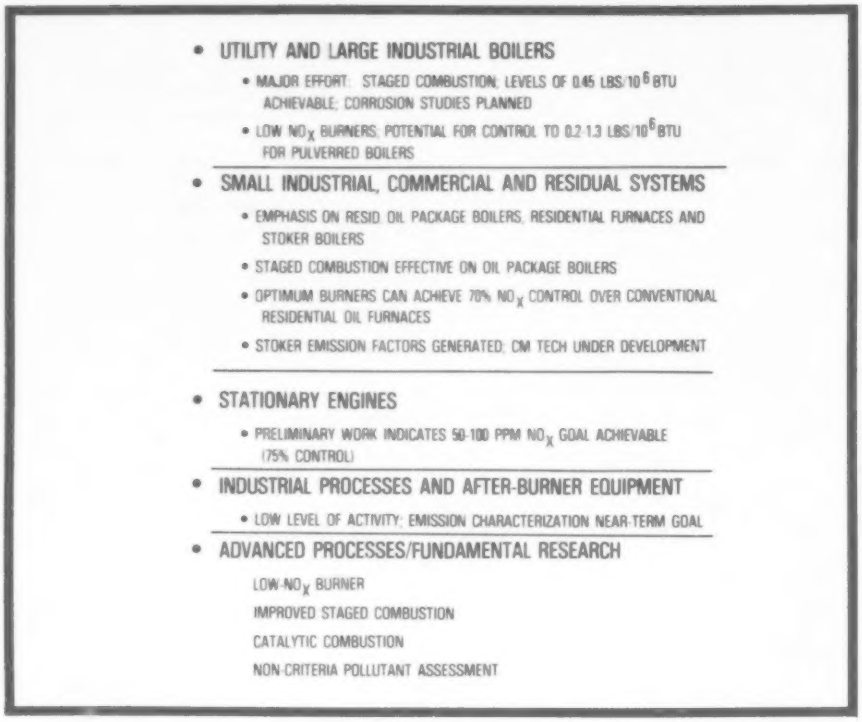
We have to be careful in implementing these techniques since it is possilble to aggravate other pollutant emission problems. We could, for example, increase emissions of carbon monoxide or particulate matter if we drastically lower excess air. Or we could lower thermal efficiency with approaches such as flue gas recirculation. These techniques can also lead to operating problems, since in some cases boilers will not be operated under the conditions that they are designed for.

However, the results of our program to date indicate that if one is careful about the particular control technology and the design parameters utilized, each of these potential problems is controllable.

NO_x COMBUSTION MODIFICATION PROGRAM

Let us now discuss the ongoing nitrogen oxide combustion modification program. I will discuss this program by source area. Figure 8 illustrates some of our efforts and outputs for the following combustion sources: utility and large industrial boilers; small industrial, commercial, and residual systems; stationary engines; and industrial processes and after-burner equipment.

In the utility and large industrial boiler area, the program's major effort has focused on staged combustion approaches. By utilization of this combustion modification technology, which involves adding combustion air sequentially in more than one location to minimize total oxygen requirements and combustion temperature, control levels of 0.45 $lbs/10^6$ Btu appear achievable. We are presently planning corrosion tests to ascertain whether boiler tube corrosion is an inherent problem. It has been postulated by some that the reducing environment associated with staged



- UTILITY AND LARGE INDUSTRIAL BOILERS
    - MAJOR EFFORT: STAGED COMBUSTION; LEVELS OF 0.45 LBS/10^6 BTU ACHIEVABLE; CORROSION STUDIES PLANNED
    - LOW NO_X BURNERS; POTENTIAL FOR CONTROL TO 0.2 1.3 LBS/10^6 BTU FOR PULVERRED BOILERS
- SMALL INDUSTRIAL, COMMERCIAL AND RESIDUAL SYSTEMS
    - EMPHASIS ON RESID OIL PACKAGE BOILERS, RESIDENTIAL FURNACES AND STOKER BOILERS
    - STAGED COMBUSTION EFFECTIVE ON OIL PACKAGE BOILERS
    - OPTIMUM BURNERS CAN ACHIEVE 70% NO_X CONTROL OVER CONVENTIONAL RESIDENTIAL OIL FURNACES
    - STOKER EMISSION FACTORS GENERATED; CM TECH UNDER DEVELOPMENT
- STATIONARY ENGINES
    - PRELIMINARY WORK INDICATES 50-100 PPM NO_X GOAL ACHIEVABLE (75% CONTROL)
- INDUSTRIAL PROCESSES AND AFTER-BURNER EQUIPMENT
    - LOW LEVEL OF ACTIVITY; EMISSION CHARACTERIZATION NEAR-TERM GOAL
- ADVANCED PROCESSES/FUNDAMENTAL RESEARCH

    LOW-NO_X BURNER

    IMPROVED STAGED COMBUSTION

    CATALYTIC COMBUSTION

    NON-CRITERIA POLLUTANT ASSESSMENT

Figure 8.
NO_X combustion modification program status

combustion can remove the protective oxidative coatings from the tubes, thereby accelerating corrosion. Therefore, corrosion tests are considered important.

LOW NO_X BURNER WORK

Perhaps our most encouraging activity in the NO_X program is our work in the low-NO_X burner area, redesigning pulverized coal burners to more carefully combust coal. Experimental results have indicated that NO_X levels of 0.2 to 0.3 lbs/10^6 Btu are achievable. This represents over 70-percent control of an uncontrolled coal-fired boiler. Since such burner technology appears inherently inexpensive, this could be the answer to low-cost nitrogen oxide control from both industrial and utility pulverized-coal boilers. If we receive the increased fiscal year 1978 funding that I mentioned earlier, we will be able to proceed on an orderly demonstration program to evaluate this approach at sizes culminating in an integrated full-scale demonstration program.

In the small industrial, commercial, and residual system area, our program emphasis has focused on residual oil-package boilers, residential furnaces, and coal-stoker boilers. We have demonstrated that staged combustion is an effective control approach on oil-package boilers. Preliminary information indicates that optimum burners can achieve 70 percent NO_X control over conventional burners for residential distillation oil furnaces. Our work in the coal-stoker area has been limited to development of emission factors for existing designs. A combustion modification technology program is presently under development for this increasingly important class of coal boilers.

Stationary internal combustion engines are a major source of nitrogen oxide emissions, mainly because of their widespread use as the prime mover for pipelines and gaslines around the country. Preliminary work by IERL/RTP indicates that it may be possible to lower nitrogen oxide concentrations in combustion gases to 50-100 ppm. This would represent an overall NO_X control of 75 percent and a substantial improvement in both NO_X efficiency and overall energy conversion efficiency to the presently available control technology, which involves introduction of water to the combustion zone.

In the industrial processes and after-burner equipment area, we have a relatively low level of activity due primarily to limitations in funds. Our near-term goal in this area is to characterize NO_X and other emissions for these facilities.

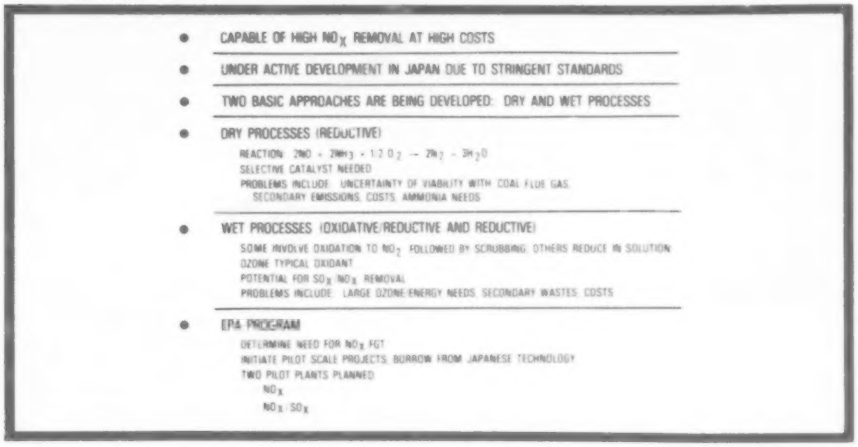
ADVANCED PROCESSES FUNDAMENTAL RESEARCH

I would also like to mention briefly some of the activities in the advanced processes fundamental research portion of the combustion modification program. This is the part of the program where the low-NO_x burner was originally conceived and will now be tested under the utility and industrial boiler portion of the program. Presently, activity is focused on improved staged combustion control technologies and catalytic combustion approaches which promise enhanced NOx removal efficiencies. Also, within this program area is our non-criteria pollutant assessment activity, which aims at determining the magnitude of emissions and effluents other than those of the regulated pollutants from various combustion sources.

Now let me briefly describe the NO_x flue gas treatment research and development program (Figure 9). One might ask, in light of the comprehensive combustion modification program I have just described, "Who needs flue gas treatment?" and "What is the advantage of this technology over combustion modification?". The only identifiable advantage in my mind is that this approach has the potential for very high NO_x removal efficiencies, which could conceivably be required if standards tighten in the years ahead.

Figure 9.

NO_x flue gas treatment program



- CAPABLE OF HIGH NO_x REMOVAL AT HIGH COSTS
- UNDER ACTIVE DEVELOPMENT IN JAPAN DUE TO STRINGENT STANDARDS
- TWO BASIC APPROACHES ARE BEING DEVELOPED: DRY AND WET PROCESSES
- DRY PROCESSES (REDUCTIVE)
  - REACTION: $2NO + 2NH_3 + 1/2\,O_2 \rightarrow 2N_2 + 3H_2O$
  - SELECTIVE CATALYST NEEDED
  - PROBLEMS INCLUDE: UNCERTAINTY OF VIABILITY WITH COAL FLUE GAS, SECONDARY EMISSIONS, COSTS, AMMONIA NEEDS
- WET PROCESSES (OXIDATIVE/REDUCTIVE AND REDUCTIVE)
  - SOME INVOLVE OXIDATION TO NO_2 FOLLOWED BY SCRUBBING, OTHERS REDUCE IN SOLUTION
  - OZONE TYPICAL OXIDANT
  - POTENTIAL FOR SO_x NO_x REMOVAL
  - PROBLEMS INCLUDE: LARGE OZONE/ENERGY NEEDS, SECONDARY WASTES, COSTS
- EPA PROGRAM
  - DETERMINE NEED FOR NO_x FGT
  - INITIATE PILOT SCALE PROJECTS, BORROW FROM JAPANESE TECHNOLOGY
  - TWO PILOT PLANTS PLANNED
    - NO_x
    - NO_x/SO_x

DRY AND WET PROCESSES

However, we pay the price for this high removal efficiency in terms of high capital and operating costs and system complexity relative to combustion modification technology. These approaches are under active development in Japan due to the stringent ambient and emission standards for nitrogen oxides there. Two basic approaches, dry and wet processes, are being developed. The dry processes are the simpler of the two and generally involve a chemical reduction reaction. Typically, ammonia is used as the reductant and a selective catalyst is needed to reduce nitrogen oxide to elemental nitrogen and oxygen. Problems with this approach include uncertainty regarding the viability of this process for coal flue gas, the possibility of secondary emissions (such as ammonium sulfate), and potentially high costs associated with capital expenses and reagent needs.

Wet processes are generally more complex and can involve either oxidative/reductive or reductive chemistry. Some of the processes involve oxidation to nitrogen oxide followed by a scrubbing step; others reduce the nitrogen oxides in solution. For the oxidative/reductive approach, ozone is a typical oxidant. The main advantage of this class of processes is the potential for combined sulfur oxide and nitrogen oxide removal. Problems include large ozone and energy needs for the oxidative/reductive process and the production of secondary wastes and high costs for all versions of the wet processes.

The EPA program in this area involves piloting promising processes for treating flue gas from coal combustors, borrowing heavily from Japanese technology on oil-fired boilers. Two pilot programs are in the final contractor selection phase at this time. One will involve nitrogen oxide removal only; the other will investigate concurrent removal of nitrogen oxide and sulfur oxide.

FINE PARTICULATE CONTROL

I would now like to summarize the status of our fine-particulate control technology program. First a little background information. Fine particulates are health hazards because they are airborne for extended time periods, can penetrate deeply into the lung, and can act as transport agents for other pollutants. Our research, development, and demonstration program includes the following major areas:

- Improvement of characterization of present technology, e.g., electrostatic precipitators, scrubbers, fabric filters
- New ideas/novel devices
- High temperature/high pressure control technology
- Collectability of dust
- Control from low-sulfur coal combustors

ELECTROSTATIC PRECIPITATOR EVALUATION

Our program is actively evaluating the potential for electrostatic precipitators as high-efficiency fine-particulate control devices. We have characterized precipitators for seven particulate sources and developed a math model which characterizes precipitator performance as a function of particulate characteristics. We have concluded that precipitators offer the possibility of high fine-particulate control when there is no ash resistivity problem. Precipitators are very sensitive to the chemistry of the ash they must collect. For example, for low-sulfur coal combustion facilities, the ash generally is of a low resistivity; there is not sufficient trioxide to raise the ash conductivity, thereby leading to collectability problems. Our program is actively considering ways of upgrading precipitator performance when the ash has less than optimum resistivity. We are actively evaluating fly-ash conditioning agents such as sulfur trioxide and ammonia. We are also evaluating the possibility of precharging the flue gas upstream of the precipitator in order to improve the collectability of the ash. We are presently planning a pilot demonstration of an attractive precharging approach. We are carefully coordinating our program with the Electric Power Research Institute, which is also active in this area.

SCRUBBER EVALUATION

We are also evaluating and developing various scrubber devices for removal of fine particulates from combustion facilities. We have evaluated 10 devices on a variety of particulate sources and currently find a consistent pattern where fine-particulate removal efficiency is highly dependent on pressure drop (and therefore energy requirements) of the scrubber device. Generally, the higher the pressure drop the better the fine-particulate removal efficiency. However, at least one scrubber type; namely, the turbulent contact absorber (TCA), has appeared uncharacteristically efficient in fine-particulate removal. Our studies have indicated that a condensation mechanism is responsible for this good performance. We are evaluating this mechanism more carefully and hope to be able to apply it to other scrubbers in other facilities. We are also piloting a flux force/condensation scrubber which uses a condensation mechanism for efficient fine-particulate removal. Recent data indicate that scrubbers may be limited in their fine-particulate performance by mist eliminators. Mist eliminators are designed to avoid the entrainment and carryover of scrubbing liquors from the scrubber into the existing flue gas. It appears that inefficient mist eliminators on commercial units have allowed such entrainment, thereby leading to carryover of particulates with subsequent degradation of fine particulate removal performance. Studies continue in this area.

FABRIC FILTRATION EVALUATION

Fabric filtration is being evaluated as a fine-particulate control scheme. We have tested filters applied commercially to three sources and find that fabric filtration is quite efficient down to 0.3 micron. These filters have similar energy requirements between the low-energy usage precipitators and the high-energy usage scrubbers. Our present program is aimed at increasing the applicability, operability, and economic desirability of these very promising devices. We are presently planning to be involved in a 350 megawatt demonstration program applying fabric filtration to a low-sulfur coal utility boiler. This will be the first commercial operation of a low-sulfur coal fabric filtration combination. Our program has also been evaluating new ideas and novel devices for the removal of fine particulates from various sources. Many of these devices have been tested at bench scale, and the most attractive devices are scheduled for pilot scale testing, pending availability of funds.

As we mentioned at last year's conference, we are developing particulate control technology capable of operating in high temperature and high pressure regimes. Pressurized fluidized bed combustion and low Btu gasification technologies require particulate control under these difficult conditions for both environmental and turbine protection. We have defined performance requirements and are evaluating various concepts and devices. Our present emphasis is on high temperature precipitators, bag houses, and granular bed filters. It is too soon to tell whether any of these devices will economically remove particulates at sufficiently high efficiency.

MOBILE TEST UNITS

We have also actively pursued the development and construction of particulate control device test units mounted on trailers, enabling us to collect and evaluate particulate control data from a variety of sources. We have constructed mobile test units of electrostatic precipitators, scrubbers, and fabric filters which allow us to determine the best control device for a given application and its associated dust problem.

Over the past year we have initiated a program to evaluate and control fugitive dust problems. Fugitive dust emissions from many energy and industrial sources can be very serious. Our present program is aimed at defining the magnitude of the problem and the alternative control technologies that may be applied.

A final element of our program is the control of particulates from low-sulfur coal combustors. This is not a new or separate part of our program, but actually incorporates our ongoing work in other areas. However, we find it helpful to focus on this major problem afflicting those utility and industrial sources that must meet particulate standards and burn low-sulfur coal. Our emphasis at this time is on the development of fabric filtration and modified electrostatic precipitators for cost effective particulate control from these sources.

WASTE AND WATER

The final technology area I will discuss is the waste and water program. This program includes the development of control technology for solid and liquid effluents from conventional energy systems and their associated control devices. It includes disposal of flue gas cleaning wastes, water recycled/treatment of the various power plant effluents, development of improved cooling tower technology, and evaluation and development of waste-heat utilization approaches. In the flue gas cleaning waste area we have a very active and comprehensive program in characterizing environmental problems associated with flue gas desulfurization sludge disposal. The program is also actively evaluating various control approaches to minimize potential impact as well as to investigate possible utilization approaches, such as the production and sale of gypsum from the sludge end product. We are evaluating problems associated with fly ash disposal. In the water recycled/treatment area we are presently completing a study of the overall material balance of the various water streams in a power plant with the aim of minimizing makeup water requirements and subsequent water pollution. We are investigating alternatives to chlorination for condenser fouling control and are evaluating the problems associated with coal pile drainage. We are also assisting the EPA Effluent Guidelines Division in identifying reasonable control technology for toxic effluents from steam electric plants.

In the cooling tower technology program we have an ongoing program evaluating wet/dry and dry cooling towers, aimed at minimizing water consumption and some of the drift and blowdown problems of wet towers. We are also planning a program to evaluate the impact of saltwater drift from wet towers and appropriate control technology to ameliorate such problems. Finally, we have a limited program in the waste-heat utilization area, aimed at finding cost effective and reasonable uses of the large quantity of waste heat associated with power plants. We have ongoing activities in the agricultural and aquacultural areas.

In conclusion, I believe the results of the conventional fossil fuel control technology program we have discussed this afternoon will go a long way to help our nation compatibly achieve two of its most important goals: energy availability and environmental protection. This session is now open to questions from the audience. I will ask our distinguished panelists to respond.

FRANK T. PRINCIOTTA

B.S., Chemical Engineering, New York City College; certificate in Nuclear Engineering Graduate Studies, Oak Ridge School of Reactor Technology. Project Engineer and Reactor Engineer for U.S. Atomic Energy Commission. In private industry directed government sponsored research and development programs in nuclear power supplies and biomedical devices. While Chief of Engineering Test Section, Control Systems Division, EPA, directed programs to develop processes for control of sulfur oxide and particulate air pollution. Currently, Director, Energy Processes Division, Office of Energy, Minerals and Industry, Office of Research and Development, EPA, Washington, DC; responsible for planning and coordinating programs to develop and improve technology on control and abatement of adverse impacts from energy production and utilization systems.

questions & answers

Ms. Patricia Smith
Northern Ohio Lung Association

Mr. Ken Wilzbach
Argonne National Laboratory

Mr. Steven Slater
Tufts University

Dr. Edward S. Rubin
Carnegie-Mellon University

Mr. Joe Selmiczi
Dravo Corporation

QUESTION: For utility-size boilers, would you consider FGD as an intermediary solution to be supplanted by fluidized bed combustion? Will fluidized bed combustion take the place of scrubbers?

RESPONSE: Mr. Frank T. Princiotta, (EPA)

Fluidized bed combustion appears to be competitive with flue gas desulfurization as far as cost is concerned. This is unusual. Most of the competition such as low Btu gasification and unrefined coal for baseload utility systems is unattractive relative to flue gas desulfurization.

Fluidized bed combustion units will not make any commercial impact in the utility field before 1990. Just go through the ERDA and industrial timeliness, and you will find that there will not be a commercial facility on-line until 1990. At that time my personal assessment is that pulverized coal with scrubbers will be very competitive with fluidized bed combustion, and it is very unclear to me which of these technologies will prevail. It is too soon to tell.

Does anyone want to comment on that?

RESPONSE: Mr. Gerald G. McGlamery, (TVA)

Again, from a utility standpoint, you are pretty close to being right. We do not see any fluidized bed combustion boilers within the near term, but of course, TVA is actively pursuing FBC technology by a separate plan of its own. I think in the last 6 months we have announced about a $4 million effort to look at a full-scale, 200 megawatt fluidized combustion boiler in the TVA system. We just cannot really be sure if that is going to take the place of scrubbers or just going to be a parallel effort. Scrubbers are cost competitive, and they are not just going to go out the window.

QUESTION:

By the same token, what is the time frame for commercialization of regenerable flue gas desulfurization?

Julian W. Jones

RESPONSE: Mr. Richard D. Stern, (EPA)

How about as soon as possible? The ACP process, which should be demonstrated by 1981, is a very significant process which we want to accelerate.

QUESTION:

This is aqueous carbonate?

RESPONSE: Mr. Stern

Yes. The Wellman-Lord process is very close to commercialization now. However, we do need to demonstrate it conclusively on the first coal-fired utility, and we hope to get that test program started within 1 month. In that area, Public Service of New Mexico has already initiated orders; in fact, they have approximately 700 megawatts of Wellman-Lord capacity presently under construction with another 1000 megawatts ordered.

There has been a great deal of progress in the area of magnesium oxide. There is one commercial unit that is expected to start up any time at Philadelphia Electric. One of the things we would like to do with this initiative money is to accelerate magnesium oxide scrubbing technology even more so with another demonstration. Depending on the results of this 120 megawatt magnesium oxide scrubbing facility at Philadelphia Electric, there is another approximately 700 megawatts of magnesium oxide technology that may be in the offing. I feel we are very close to commercializing regenerable FGD.

QUESTION:

Utilities in Japan are injecting ozone into flue gas to oxidize NO to NO_2 as part of a control strategy for dealing with NO_x. We have some evidence that ozone also oxides SO_2 to SO_3 at temperatures in the range of about 400 degrees Fahrenheit.

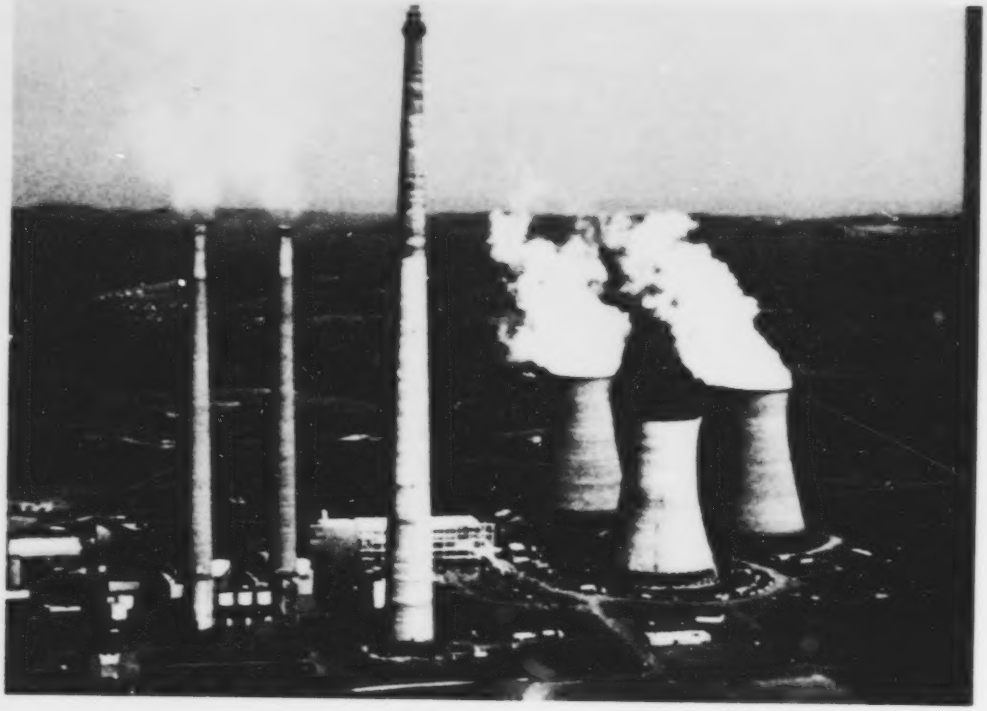
Considering the recovery of waste heat, would ozone generation be an attractive technology for controlling NO_x and SO_x simultaneously? And if not for waste heat, consider a portion of the flue gas being exposed to ozone in order to produce some SO_3; would the reduction of resistivity of the fly ash make this attractive?

RESPONSE: Mr. Stern

The cost of ozone is extremely high, and for NO_x control alone you would have a stoichiometry of one. It would not only use a great deal of energy, but would also cost a great deal of money. So for NO_x control alone, we do not see ozone as being a strong contender. However, for the simultaneous processes, the energy and cost penalty of ozone may perhaps be compensated for by the fact that you may be able to control both SO_x, SO_2, and NO at a relatively lower cost in energy that you could individually.

As to oxidizing SO_2 to SO_3 with the ozone, which you would certainly do, that would be recovered primarily as sulfuric acid; whether or not you could have a wet process that would recover the sulfuric acid as well as the nitric acid or the nitrates, could be a real complication.

Our proposals do not include this option; however, the Japanese people are looking at it right now.



QUESTION:

This morning Dr. Stephen Gage alluded to something I would like someone in the FGD group to pick up. That is the possibility of partially bypassing an FGD system using a precipitator for particulate control and using the hot flue gases to reduce the energy requirement for reheat.

Some utilities are already doing this. One of the benefits seems to be that if you view emissions on the basis of megawatt of useful electricity produced for sale rather than coal coming in the front of the boiler, you are better off on that sort of normalization basis.

Is it your view that this sort of an option would be precluded by the sorts of deliberations currently in Congress? Does best available technology mean 100 percent of all flue gas to the "best" you could do?

RESPONSE: Mr. Princiotta

Let me first clarify what Dr. Gage said. He was referring to the combination of coal cleaning and flue gas desulfurization. I think he was suggesting that if you can clean the coal relatively inexpensively and then treat a portion of the resulting flue gases with a scrubber, the remaining untreated portion would still be hot and could be used for reheat.

QUESTION: Would the result be the same?

RESPONSE: Mr. Princiotta

Yes, it would. I commented earlier that the possibility of revised new source performance standards for coal generators would obviously tighten the requirement. If such a standard is implemented, we are talking on the order of 85 to 90 percent control. This of course, makes it more difficult to have any flue gas stream that is untreated. In other words, even if you threat part of the flue gas with 100 percent SO_2 removal efficiency, you are limited in this case to only a maximum of 10 percent, and that is nominal for reheat purposes. So I think the tendency would be to make that approach a little more difficult.

QUESTION: Do any of the panelists have any comments on that?

RESPONSE: Mr. Julian W. Jones, (EPA)

I did have one comment. I think that coal cleaning, in combination with flue gas desulfurization, depending on the outcome of the regulatory dilemma, could be a viable approach. You could use the flue gas bypass, the partial scrubbing, and then use the remainder for reheat. If you have to go to a 90 percent removal based either on incoming or total gas being generated by the plant, then it really becomes impractical.

RESPONSE: Mr. Princiotta

Let me just mention that although the reheat aspect of the concept may be hurt by any tightened standards, in my view at least, the combination of coal cleaning and FGD still looks favorable. As Dr. Gage pointed out, there is no more inexpensive way of removing a given amount of sulfur from coal as physical coal cleaning; so the combination would still make a lot of sense on a case-by-case basis.

QUESTION:

I would like to comment on the unsaturated mode of scrubbers operating on lime with magnesium oxide. I think this mode is further ahead than Mr. Princiotta implied. Several demonstrations – including the Bruce-Mansfield Power Plant, which has been operating in an unsaturated mode for over a year, and the Conesville Power Plant of Columbus in Southern Ohio in operation for several months – have proved that when common water chemistry is considered, the unsaturated mode can be maintained. What do you think?

RESPONSE: Mr. Michael A. Maxwell, (EPA)

I think it is undeniably a fact that those systems have operated well. We have been getting anomalous data at Shawnee which indicates that some of the earlier concepts we had of the unsaturated operation perhaps were not fully founded. So even though those systems are operating well, we still feel that there are some gaps in the information that we would like to see answered.

technical discussion

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THE FEDERAL INTERAGENCY FLUE GAS DESULFURIZATION PROGRAM

Gerald G. McGlamery
Office of Agricultural and Chemical Development
Tennessee Valley Authority
Muscle Shoals, Alabama

Richard D. Stern and Michael A. Maxwell
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina

INTRODUCTION

Flue gas desulfurization (FGD) is the term used to denote processes for removal of sulfur dioxide (SO_2) from flue gas, usually by means of a gas scrubbing operation. FGD is the major near-term technological approach to meeting new source performance standards when utilizing high-sulfur coal supplies. If a policy of rapid expansion in the use of coal is to be successfully implemented, it is essential that FGD technology be fully developed for application in the utility and industrial sectors.

In the Federal energy/environment research and development program, FGD technology development has been given a high priority. Studies by EPA indicate that FGD is competitive in cost with advanced control methods, such as chemical coal cleaning and fluidized bed combustion; therefore, FGD should play an important role in controlling emissions even in the 1990's.

This technology has progressed rapidly by taking advantage of financial aid passing through the Federal interagency program. Several FGD studies, pilot plants, prototypes, and demonstration-scale facilities have been funded by the Environmental Protection Agency (EPA). Although progress had been achieved in FGD development prior to 1975, the overall pace of development was increased by the initiation of the Federal interagency effort.

The Federal program through EPA's Industrial Environmental Research Laboratory in Research Triangle Park, North Carolina (IERL-RTP), has aimed at demonstrating reliable and cost-effective FGD processes, including both nonregenerable (throwaway) and regenerable (saleable byproducts) systems. EPA has been aided in this effort by at least two other Federal organizations, the Tennessee Valley Authority (TVA) and the U.S. Bureau of Mines (BOM). For example, EPA's key program in the nonregenerable area is the lime-limestone prototype test program at TVA's Shawnee Steam Plant (near Paducah, Kentucky), and a major regenerable (citrate) process demonstration unit is to be built based on pilot-plant work by BOM.

Other major activities in the area of nonregenerable technology include full-scale demonstrations of double-alkali scrubbing systems, and a comprehensive program in scrubber sludge disposal. In the regenerable FGD area, an aggressive program has been pursued toward development of processes capable of producing saleable sulfur products. In addition to the work of BOM on sodium citrate scrubbing, full-scale demonstrations of the Cat-Ox (producing 80% sulfuric acid), Wellman-Lord (W-L)/Allied Chemical (producing sulfur), magnesium oxide (producing sulfuric acid), and the aqueous carbonate (producing sulfur) processes have been undertaken.

A number of supporting studies have also been initiated through the interagency program for both nonregenerable and regenerable processes. Included are design and cost evaluations for sludge disposal and advanced SO_2 removal technologies, byproduct marketing studies, bench-scale research on key processing steps, investigation of reductants for SO_2 to sulfur, energy optimization studies, and a comparison of utility/industry equipment reliability/availability.

In addition to these efforts to develop technology, a companion technology transfer effort is also underway. Through a series of briefings, symposiums, capsule reports, summary reports, and a survey of FGD installations, the industry is being aided in its efforts to stay abreast of the rapidly advancing FGD technology.

TECHNICAL DISCUSSION

Lime-Limestone Activities

Lime-limestone processes are particularly important in the overall FGD story. Over 60% of the FGD systems, which have been built, are under construction, or are being planned for service by the early 1980's, are lime-limestone processes.

The Shawnee Program. An important part of the lime-limestone effort involves the operation of a prototype scrubbing test facility at Shawnee Steam Plant. This versatile facility allows comprehensive testing of up to three 10-MW scrubber types under a variety of operating conditions. Bechtel Corporation of San Francisco designed the test facility and directs the test program, and TVA constructed and operates the facility.

The major concerns of the utility industry to date regarding lime-limestone scrubbing have centered around scaling and plugging potential, the large quantities of waste sludge generated, and the high costs (capital and operating) of scrubbing. It is toward these areas of concern that the Shawnee program has been directed.

The major objectives of the original 2-year test program were: (1) to characterize fully the effect of important process variables on SO_2 and particulate removal; (2) to develop and verify mathematical models to allow scaleup to full-scale scrubber facilities; (3) to study the technical and economic feasibility of lime-limestone scrubbing; and (4) to demonstrate long-term reliability. Based on the initial test results, comments from utilities and FGD system vendors, and particularly

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on results from EPA pilot-plant support studies, it became apparent that additional information was needed to optimize lime and limestone systems in the areas of: sludge disposal, improved reliability, variable-load operation, and improved economics. Therefore, in 1974 the Shawnee program was extended and the scope was expanded to investigate promising equipment and process variations to: (1) minimize costs, energy requirements, and quantity (and improve the quality) of the sludge produced; (2) maximize SO_2 removal efficiency; (3) develop a design/economic study computer program; and (4) improve system control and operating reliability, especially in the mist eliminator area. Of particular interest were studies of forced oxidation, increased alkali utilization, and MgO or other additives to increase SO_2 removal efficiency and to force subsaturated gypsum operation.

The Shawnee program has made major contributions toward improvement of lime and limestone scrubbing technology. The most significant results to date include: (1) demonstration that conventional lime-limestone systems can be operated reliably on a 10-MW level (two separate reliability problems have been identified--scaling and accumulation of soft mud-type solids--and methods to control each have been demonstrated); (2) mud-type solids deposition was shown to be a strong function of alkali utilization and at high utilization (greater than about 85%) these solids are much more easily removed; (3) equipment or process variations were demonstrated which individually improved alkali utilization, improved SO_2 removal efficiency, and favorably influenced the system chemistry; and (4) development of useful industrial tools, such as the design/economic study computer program and the computerized Shawnee data base.

The EPA Pilot FGD Scrubber Program. The FGD pilot plant operated by IERL-RTP consists of two scrubbers having a flue gas capacity of about 0.1 MW. They have been in operation since 1972 for the principal purpose of providing in-house experimental support for EPA's larger, prototype scrubber test facility at Shawnee Steam Plant. The IERL-RTP scrubbers have 1% of the capacity of the Shawnee prototypes and are 1/1000 scale. In addition to supporting Shawnee, the pilot plant also provides IERL-RTP with the capability to independently evaluate new concepts in lime-limestone scrubbing technology.

Results from this pilot unit indicate that forced oxidation limestone scrubbing can be achieved in a two-stage scrubbing system promoting formation of gypsum, a more desirable form of calcium solids, and improving limestone utilization. An extension of this work has recently been undertaken at the Shawnee test facility. Further tests at IERL-RTP have been directed toward achieving the oxidation step in a single-stage scrubber, and information has been developed toward application in larger commercial scrubbing systems. Thus far, it has been demonstrated in the IERL-RTP scrubber that single-stage forced oxidation can be achieved with no loss of SO_2 removal efficiency.

A study of the formation of solid solutions in lime-limestone scrubbers was completed which verified earlier findings made at IERL-RTP that sulfate can be purged with the solids at low oxidation levels while maintaining subsaturated liquor. Attempts to apply this "subsaturated operating mode" to large-scale scrubbers are being made at Shawnee and Louisville Gas and Electric's (LG&E) Paddy's Run lime scrubber.

The data obtained from the IERL-RTP scrubber have been analyzed, together with the Shawnee data, to develop comprehensive mathematical models for predicting SO_2 removal efficiency in lime and limestone scrubbers as a function of basic process variables, such as liquid to gas ratio, SO_2 concentration, pH, magnesium concentration, and pressure drop.

Bahco Program. The AB Bahco Ventilation (Sweden) lime scrubbing process has been installed on about 20 small industrial-size oil-fired boilers outside of the United States. Research-Cottrell is the licensee in the United States for this process. The Bahco system appears particularly suited for small industrial applications and, in fact, is manufactured in standard sizes of about 5-50 MW equivalent. The system is readily adaptable to a high degree of automation. Although automation results in a somewhat higher capital investment cost initially, labor costs are low in that the same personnel operating the boiler can also handle operation of the FGD system.

The Air Force contracted with Research-Cottrell to install a Bahco system for SO_2 and particulate control on up to seven small coal-fired heating boilers (approximately 21 MW equivalent total) at Rickenbacker Air Force Base near Columbus, Ohio. EPA is sponsoring a 2-year test program on this system. Although numerous mechanical problems have been encountered since startup in March 1976, results generally have been promising. Acceptance tests have not been run yet but they are planned shortly, after boiler control problems are resolved. Results to date indicate that despite the high particulate loading, which at times has been predominately very small sooty particles, design specifications for both the particulate and SO_2 removal efficiency have been exceeded consistently.

LG&E Scrubber Test Program. In November 1974, results from the IERL-RTP pilot-plant testing were reported which showed that lime and limestone SO_2 scrubbers could be operated subsaturated with respect to dissolved $CaSO_4 \cdot 2H_2O$ (gypsum). This mode of operation avoids the problem of gypsum scaling on the scrubber internals. Subsequent investigation indicated that at least two commercial scrubber systems were operating subsaturated with respect to gypsum, one at the Mitsui Aluminum Plant in Omuta, Japan, and the other at Paddy's Run Station of LG&E.

Because of the success at LG&E and because of EPA's interest in studying the subsaturated mode of operation, a program was undertaken at LG&E in the spring of 1976 to evaluate operational and chemical factors identified by scrubber testing at IERL-RTP and Shawnee which appear to have an effect on subsaturated operation. The test program at LG&E consists of four phases of testing: (1) carbide lime testing (to establish baseline conditions); (2) commercial lime testing (to compare with carbide lime and to establish more widely applicable baseline operating conditions); (3) reaction tank modification testing (to examine the effects of residence time); and (4) MgO/Cl addition testing (to examine the effects of magnesium addition and increased chloride levels).

The carbide lime phase of the test program was initiated in October 1976 and was concluded in December 1976. No major scrubber operational problems occurred during these tests. However, there was a problem with the liquid analysis for sulfite because of an interference caused by impurities in the carbide lime. Waste sludge from the system was collected for sludge treatment/disposal tests which are being conducted in conjunction with the scrubber test program.

The commercial lime phase of the test program was initiated in March 1977. Shortly after startup, two problems were evident: (1) the interference which had occurred in the sulfite analyses during carbide lime testing was still present,and (2) scaling in the scrubber. The scaling problem is thought to be a result of high oxidation causing an excessive gypsum saturation level. It has been concluded that the carbide lime contains an oxidation inhibitor in trace quantities.

Because of the difficulties described above, the testing under the reaction tank modification and MgO/Cl addition phases is not expected to be as extensive as originally planned. However, the overall objectives of the program should be met.

High-Velocity Scrubbing and Vertical Duct Mist Elimination Pilot-Plant Program. As part of the EPA lime-limestone scrubbing efforts, TVA investigated during 1975-76 a number of washing techniques for vertical duct mist eliminators on a 1-MW pilot plant at TVA's Colbert Steam Plant near Muscle Shoals, Alabama. High-velocity scrubbing tests were also performed in conjunction with the mist eliminator test. In the program, TVA demonstrated washing techniques that permitted continuous mist eliminator performance for closed-loop lime-limestone systems running at 12.6 ft/sec (3.8 m/sec) gas velocity. Intermittent washing with fresh makeup water was successful in the lime mode; however, difficulties were encountered with this procedure when running with limestone. An alternate procedure was developed for limestone using both clarified liquor and fresh makeup water. Continuous mist eliminator performance was maintained by washing the bottom of the mist eliminator intermittently with all available clarified liquor, immediately followed by an allocated amount of allowable makeup water. The top of the mist eliminator was washed intermittently with the remaining allocation of allowable fresh water.

In general, the scrubber operated more efficiently and mist eliminator performance was improved at a higher velocity (16 ft/sec or 4.9 m/sec); however, long-term testing was conclusive only with lime scrubbing. Additional washing may be required for limestone at higher gas velocities.

Double-Alkali Activities

The double-alkali process provides an alternate wet scrubbing "throwaway" system to the more prevalent lime-limestone slurry scrubbing processes. Such systems employ a clear liquid absorbent rather than the slurry which is used in lime-limestone processes. As a result, the scrubber in a double-alkali unit is expected to be less prone to fouling and plugging problems.

The double-alkali process is now offered commercially by several companies for control of industrial and utility boilers. Process capabilities include 90% or more SO_2 removal, less than 2% energy consumption exclusive of reheat energy, close to 100% lime-SO_2 stoichiometry, and soda ash consumption in the range of 5% of the lime on a molecular basis. However, these processes may in certain instances be more costly than lime-limestone systems.

Combustion Equipment Associates (CEA) - A. D. Little (ADL) Program. The development of double-alkali technology by EPA has followed an orderly progressive pattern. After initial in-house engineering feasibility studies and laboratory experiments in 1971 and 1972, EPA contracted with ADL in May 1973 to conduct a laboratory and pilot-plant study of various double-alkali modes of operation. In early 1975 the project was expanded to include a prototype test at the 20-MW facility installed at the Scholz Steam Plant of Gulf Power Company by The Southern Company and constructed by CEA. In late 1976, agreement was reached for a full-scale utility demonstration of the process which hopefully will be started up in 1979.

Work in the laboratory and pilot plant included the study of "dilute" and "concentrated" systems, lime and limestone regeneration, sulfuric acid addition for sulfate removal, and solids characterization. Prototype testing at the Scholz Steam Plant lasted from February 1975 to July 1976, with the EPA-sponsored portion of the testing beginning in May 1975. As a whole, the prototype system performed very well and indicated that a double-alkali system could be a viable FGD system for coal-burning utilities. SO_2 removal was generally in the range of 90 to 99%.

LG&E Double-Alkali Demonstration Program. In September 1976, EPA contracted with LG&E for a cost-shared, full-scale coal-fired utility demonstration of the double-alkali process at the 280-MW Cane Run No. 6 boiler. The demonstration project consists of four phases: (1) design and cost estimation; (2) engineering design, construction, and mechanical testing; (3) startup and performance testing; and (4) 1 year of operation and long-term testing. Construction is expected to be complete by the end of 1978, and testing will begin in early 1979. A contract funded by EPA with an independent company will soon be established to design and conduct a test program at the LG&E facility to evaluate the process technically and economically.

General Motors (GM) Industrial Boiler Demonstration. GM and EPA have participated in a cooperative program to demonstrate, test, characterize, and evaluate GM's "dilute" mode double-alkali system for control of SO_2 emissions from coal-fired industrial boilers. The program was conducted at GM's industrial boiler complex in Parma, Ohio. The system, consisting of four coal-fired boilers having a steaming capacity of 320,000 lb/hr (equivalent to 32 MW electric generating capacity), was constructed and operated by GM. ADL designed and conducted the test program to evaluate the system with funding from EPA. The test program consisted of three 1-month intensive test periods and longer term nonintensive testing. Each of the intensive tests evaluated a slightly different flow scheme.

Regenerable Process Activities

Since its inception in 1970 EPA has assisted in the development of several recovery processes capable of producing sulfuric acid, elemental sulfur, or liquefied SO_2. These processes have been pursued in hopes of conserving a valuable natural resource and reducing overall SO_2 control costs. Most of the EPA efforts have been directed toward full-scale demonstrations of a number of leading processes; however, support has also been given to bench-scale and pilot-plant efforts.

Magnesium Oxide Scrubbing Program. The Mag-Ox scrubbing process--developed by Chemical Construction Company (Chemico) and Basic Chemicals, and currently offered commercially by Chemico--is one of the more promising regenerable FGD approaches. The process, which produces sulfuric acid, is widely applicable to both existing and new power plants. It is also amenable to the centralized processing concept; i.e., spent sorbent can be regenerated at a central plant capable of servicing a number of power or industrial plants.

In 1974, EPA and Boston Edison completed a cofunded demonstration program of a 155-MW-capacity scrubbing-regeneration system. Results obtained during 2 years of operation indicated: (1) SO_2 removal efficiencies in excess of 90% were obtained consistently,and (2) more than 5,000 tons of saleable sulfuric acid of high quality were recovered from the stack gas and sold commercially. A number of problems were encountered that were primarily equipment, rather than process related; however, continuous, long-term, reliable operation was not achieved.

In 1973, Potomac Electric Power Company installed a 100-MW Mag-Ox scrubbing system at its coal-fired Dickerson Station. EPA provided the Mag-Ox regeneration system for Potomac Electric's use in processing spent scrubber sorbent. Results indicate SO_2 removal efficiencies greater than 90% are possible and particulate removal of 99.6% was attained. Over 2000 tons of sulfuric acid were produced and marketed. Unfortunately due to a shortage of funds this demonstration did not run long enough to completely answer all questions regarding absorbent recycle, absorbent losses, and process reliability.

Philadelphia Electric will soon begin operating a 120-MW MgO scrubbing facility at the Eddystone unit 1. After initial startup in September 1975, this unit was shut down when the regeneration-sulfuric acid system at Olin Chemicals, Paulsboro, New Jersey, plant was permanently closed. Regeneration will now take place at an Essex Chemical's acid plant in Newark, New Jersey. EPA plans to supply consulting for startup, operation, and test program formulation.

W-L/Allied Chemical Demonstration Program. EPA and Northern Indiana Public Service Company (NIPSCO) have jointly funded the design and construction of a flue gas cleaning demonstration plant utilizing the W-L SO_2 recovery process and the Allied Chemical SO_2 reduction process to convert recovered SO_2 to elemental sulfur. The operational costs for the system will be paid by NIPSCO, and a comprehensive test and evaluation program will be funded by EPA. The demonstration system has been retrofitted to the 115-MW, coal-fired unit 11 at the D. H. Mitchell Station in Gary, Indiana.

The demonstration program consists of three phases: Phase I--the development of a process design, major equipment specification, and a detailed cost estimate--was completed in December 1972. Phase II--the final design and construction--was completed by Davy Powergas, Inc. (owner of the W-L process) in August 1976. Startup activities and acceptance testing were delayed by boiler problems which developed when unit 11 was shut down for annual maintenance. The boiler and the FGD plant are scheduled to restart in June, and integrated operation and acceptance testing will follow shortly thereafter. Phase III--long-term duration testing--will begin after acceptance.

Aqueous Carbonate Demonstration Program. EPA and Empire State Electric Energy Research Corporation (ESEERCO), a research organization sponsored by New York's eight major power suppliers, have recently contracted to fund jointly the design and construction of a demonstration of Atomics International's sulfur-producing aqueous carbonate process. The demonstration is being retrofitted to Niagara Mohawk Power Company's 100-MW coal-fired Huntley Station in Tonawanda, New York.

The demonstration will be in four phases. Phase I, the design and cost estimate, is expected to be completed by mid-1977, and Phase II, construction, by mid-1979. Acceptance, Phase III, should be accomplished by the end of 1979, at which time a 1-year test and evaluation program, Phase IV, will be initiated.

BOM Citrate Demonstration Program. EPA and BOM have entered into a cooperative agreement to pool funds and technical talents to demonstrate the citrate process which has been developed through pilot scale by BOM. A concurrent development program, carried out by an industrial consortium headed by Pfizer Chemical Company, also led to a pilot operation of the process. Based on the results of these two pilot programs, EPA and BOM have initiated the demonstration of this technology on a 53-MW coal-fired boiler at St. Joe Minerals Corporation in Monaca, Pennsylvania.

The demonstration will be in four phases. Phase I, the design and cost estimate, was completed in November 1976. Phase II, detailed design, procurement, and construction, began in March 1977 and is scheduled to be completed in mid-1978. Acceptance, Phase III, should be accomplished by the end of 1978 at which time a 1-year test and evaluation program, Phase IV, will be initiated.

Catalytic Oxidation (Cat-Ox) Demonstration Program. The Cat-Ox process is Monsanto Enviro-Chem Systems' adaptation of the contact sulfuric acid process. EPA and Illinois Power Company have been attempting to demonstrate the process on a 103-MW coal-fired boiler at Illinois Power's Wood River Station since 1970.

Detailed design, construction, shakedown testing, and performance guarantee testing were completed in July 1973. The unit met all guarantees and was subsequently accepted. Because of the shortage of natural gas, the burners were modified to allow either oil- or gas-firing, as conditions permit; however, design and startup problems have precluded successful operation and initiation of the comprehensive 1-year test program.

In view of the problems and long delays encountered, a thorough technical and economic study was made of the costs and benefits of continuing the Cat-Ox demonstration at the Wood River Station. Results of this study led to the decision to end the project in December 1976.

Ammonia Scrubbing with Bisulfate Regeneration Pilot-Plant Program. In 1970, EPA and TVA jointly undertook the development of a completely cyclic ammonia scrubbing - ammonium bisulfate regeneration process which has as its major product a concentrated stream of SO_2 which can then be used to produce sulfuric acid or elemental sulfur. This process was evaluated at a 3,000 ft^3/min (5,100 m^3/hr) pilot plant located at Colbert Steam Plant. While initial developmental efforts at the pilot unit were concentrated on the absorber, later work included investigation of all subunits of the system except the electrical decomposer. It became apparent that the process had two major problems: (1) the formation of a persistent fume which could not be consistently controlled or eliminated by reasonable control efforts, and (2) unfavorable economic projections due primarily to energy consumption by the decomposer. As a result of these problems, the development project was terminated during the summer of 1976.

Support Studies for FGD Systems

Key supporting studies in several problem areas of FGD technology have been sponsored by EPA to further the advancement and application of commercial systems. In many cases, the studies undertaken are broad general assessments which are directed toward a wide variety of potential users.

Reductant Gases. Elemental sulfur is a desirable form for recovery of SO_x because it is the minimum quantity of any FGD waste or byproduct and because of its saleability, ease of transport, and suitability for long-term storage. Production of sulfur from SO_x requires the use of a reductant for conversion of the SO_x to sulfur; to date, major emphasis has been on the use of natural gas for this purpose. In view of the current and continuing shortage of natural gas, it is imperative that other sources of reductant gas be utilized in the future. Toward this end EPA retained Battelle Columbus Laboratories to conduct process evaluation and cost estimates of gasification processes that are suited for application to FGD requirements, and to recommend avenues of continuing development and demonstration.

The project report concludes that a gasifier-based reduction system would increase significantly the complexity of the overall FGD system. However, the gasifier could be used to supply some of the energy requirements of the FGD process, such as for stack gas reheating. The report also concluded that purchased H_2S will play only a minor role as a reductant for SO_2 from power plant FGD systems. The use of H_2S will involve almost entirely byproduct streams obtained "across the fence" from a source such as an oil refinery or a natural gas processing plant, and geographical considerations will restrict this usage.

Byproduct Marketing Studies. Regenerable FGD systems produce such byproducts as sulfuric acid, sulfur and, to a lesser extent, gypsum. The purpose of this program is to develop a computer model to determine the quantities of byproduct acid, sulfur, and gypsum that would be produced at power plant sources and to analyze the markets for these byproducts.

Under interagency agreement with EPA, TVA has studied the economics of marketing sulfuric acid that could theoretically be produced from its coal-fired plants. Preliminary results in 1973 indicated that the net sales revenue of abatement acid would range from \$6 to \$9/ton of 98% sulfuric acid, and might reduce the cost of operating a power plant sulfur oxide recovery system by 10 to 20%.

Since the first report, however, the market for abatement acid has improved and a second phase of the marketing study is now underway. In this phase, TVA is considering all potential abatement acid or elemental sulfur from power plants located in the United States. Unlike the first phase, however, this is not a hypothetical model, but is based on the actual utility and sulfuric acid plant population of the region in question. Moreover, TVA's computer program considers compliance with SO_2 emission standards and identifies optimum production and distribution patterns based on freight costs and market demand. As in the first phase, the net sales revenue is to be estimated. The project was also expanded to include marketing of calcium sulfate (gypsum) in addition to sulfur and sulfuric acid. Final reports covering the marketing of abatement sulfur, sulfuric acid, and calcium sulfate should be available by the fall of 1977.

Comparative Economics of SO_2 Control Processes. The purpose of this continuing EPA-TVA project is to study the most promising SO_2 removal processes advancing toward commercialization. It includes selection of those processes which have the greatest degree of development and which are potentially attractive both technically and economically. These evaluations include preparation of flow sheets, material balances, and layouts; definition of process equipment; preparation of capital investments and operating costs; and analysis of design and economic variables for cost sensitivity analysis. Currently, this is being done for the citrate and double-alkali processes using the limestone system for comparison.

Other facets of the project address sludge disposal alternatives, evaluation of an alumina extraction process, critique of published FGD cost estimates, and studies of promising front-end fuel processing alternatives. At the present time TVA has completed information gathering, design, and costing for the citrate and double-alkali processes. Results of these studies should be available by late summer. Four sludge disposal alternatives have been evaluated, and a report of this work is almost complete. Work on the fuel processing alternatives has not yet begun.

Supporting Studies for the Magnesium Oxide Scrubbing Program. Two studies in support of magnesium oxide scrubbing have been conducted by the Radian Corporation. In the first study, Radian evaluated the feasibility of producing elemental sulfur directly from magnesium sulfite. This would expand the applicability of current magnesium oxide processes which only produce sulfuric acid. The second study is concerned with the mechanism of formation of tri- and hexa-hydrate forms of magnesium sulfite ($MgSO_3 \cdot 3H_2O$, $MgSO_3 \cdot 6H_2O$). The hexahydrate crystals separate and handle easily; the tri-hydrate crystals require less drying energy but are more difficult to separate and handle. This study has attempted to generate information on formation mechanisms and operating conditions that can be used to control the type of crystal formed.

Advanced Concepts Bench-Scale Studies. In support of FGD systems development, TVA is performing for EPA a series of bench-scale tests on individual SO_2 process steps, such as absorption, oxidation, reduction, and decomposition. In addition, research work is being performed on promising potassium and melamine scrubbing systems. Progress was achieved in developing an improved sulfite oxidizer which reduces energy consumption and improves oxygen utilization over an available Japanese device. The key steps in the cyclic potassium scrubbing-decomposition system were tested and data gathered for potential scale-up to larger pilot-plant facilities. One promising method studied for accommodating unwanted oxidation in soluble alkali scrubbing systems was to precipitate selectively barium sulfate from sulfite scrubber solutions with barium carbonate. The barium sulfate could be reduced to sulfide and this converted to barium carbonate (for recycle) and hydrogen sulfide by treatment with carbon dioxide and water; the hydrogen sulfide could be converted to elemental sulfur by the Claus process. Studies were made also on use of dilute sulfuric acid, as might be produced from power plant stack gas, in production of dilute phosphoric acid, and on some energy-efficient methods for converting dilute phosphoric acid into useful fertilizer products.

Comparison of Availability and Reliability of Equipment Utilized in the Electric Utility Industry. For the past several years one of the major objections of the utility industry to installing FGD systems has been that reliability/availability of FGD systems is much lower than for other major utility equipment items, such as boilers, turbines, generators, electrostatic precipitators, and gas turbines. It is desirable that good information and data on this question be gathered so that a valid comparison of performance can be made.

To meet this need and to provide information as input for a current National Academy of Sciences study of SO_x control technology, a study by Radian was initiated as a jointly sponsored project of EPA and the Council on Environmental Quality. The objectives of the study are to: draw together all available information on the reliability/availability of both FGD systems and other equipment components used in the electric utility industry; and to develop a basis and model and to make the performance comparison.

The desired information was assembled and a model for comparing these dissimilar types of equipment was developed. The Figure of Merit, selected as a basis for the comparison, incorporates such factors as reliability, development status, and repair effort. The major conclusions of the Radian study include: a statistically meaningful comparison of reliability/availability of these components cannot now be made, primarily because of the small number and short service time of FGD system data (a meaningful comparison can probably be made in 1979); the comparison model or Figure of Merit provides a better basis of comparing or ranking dissimilar types of equipment or systems than any single parameter now being recorded; and the mechanical reliability of some types of conventional equipment now being used by the electric utility industry is not much different from similar items used in FGD systems.

Technology Transfer

Engineering Applications/Information Transfer (EA/IT). EPA has initiated a program to disseminate effectively FGD technology data and information to meet the needs of the user community. In the past EPA has attempted to meet its technology/information dissemination responsibility primarily through periodic symposiums, reports, and personal communications. These activities will be continued, but they will be augmented by a comprehensive EA/IT program now being carried out jointly by EPA and contractor personnel to assure the efficient and effective dissemination of information on pollution control technology to all concerned sectors of the Nation.

Materials being prepared under the expanded EA/IT program include (1) a Summary Report on the Wellman-Lord FGD process, (2) a series of quarterly reports of FGD research, development and demonstration sponsored by EPA, (3) a Lime Scrubbing FGD Data Book, and (4) a Limestone Scrubbing FGD Data Book. These last two are being prepared as a cooperative effort between EPA and the Electric Power Research Institute (EPRI).

One specific facet of the comprehensive EA/IT program is the design, development, and implementation of a series of three Cost/Reliability Handbooks. This series of handbooks will provide one-source availability of pertinent FGD data and information gathered from past and present FGD efforts within EPA, TVA, EPRI, the utility industry, FGD vendors, and other foreign and domestic organizations. The objective of the handbooks is to assist potential users in choosing an FGD system for a specific location with specific requirements/restrictions. The first handbook will cover strategies in choosing among the methods of meeting emission standards, such as clean coal, FGD, or coal cleaning. The second handbook will aid in choosing among the available FGD systems. The third handbook will serve as a guide for optimizing equipment selection within an FGD system.

In another effort of the EA/IT program, nonutility combustion sources that are applying or considering the application of various strategies for control of SO_x emissions have been surveyed. Meetings were held with regulatory agencies and industrial representatives in the selected study areas to determine the various strategies/technologies in use and to conduct surveys of selected plants. The overall applicability of each control technology to each study area has been assessed and the information gathered has been brought together into a nonutility survey report.

Survey of Utility FGD Installations. To meet the continuing demand for technical and economic data on operational, under construction, and planned future units, EPA has employed PEDCo-Environmental to monitor this field of technology and prepare periodic reports for use by utilities, system vendors and designers, and regulatory authorities. In addition to detailed technical reports, PEDCo is providing bimonthly status reports indicating the number of each type of SO_2 control system in operation, under construction, or planned in the United States, and the megawatt capacity controlled or to be controlled. The bimonthly status report gives technical and economic information on all known U.S. utility FGD systems categorized in 15 tables and 4 appendices to promote ease of use.

Symposiums, Industry Briefings, Capsule Reports, and Summary Reports. EPA continues to disseminate information through its traditional outlets, such as the periodic FGD symposiums, industry briefings, capsule reports, and project summary reports. Six symposiums have now been held, the last one in March 1976. The next symposium is scheduled for November 8-10, 1977, in Hollywood, Florida. Progress on lime-limestone technology has been reported through industry briefings, the last one in October 1976. Thus far, three capsule reports have been issued on the EPA-TVA-Bechtel Shawnee program. Numerous project reports and papers covering completed work on FGD sponsored under the Federal interagency energy/environment program are listed in the bibliography.

PROGRAM DISCUSSION

There is a considerable amount of work yet to be done in the Federal interagency FGD program; however, a number of significant results already have been derived.

In the area of lime-limestone slurry scrubbing, the Shawnee program has provided considerable experience and data which can be used to advance the technology. Significant progress has been achieved on workable materials of construction, pump selection, mist eliminator design and washing techniques to avoid equipment scaling and plugging, alkali utilization, variable-load operation, flue gas characterization, flyash-free operation, and overall process reliability. Data from this program have been reported extensively to the industry and are available for use in designing the new lime-limestone systems to be installed around the country. If the results from Shawnee can be translated to larger, full-scale systems, the program will have served the industry well.

The results of the IERL-RTP pilot-plant test scrubber are also significant. Often, findings in this program (such as subsaturated mode of operation, effects of chloride content of coal, oxidation, and alkali utilization studies) have been the first step toward improving lime-limestone systems. Much of the present and future Shawnee test program activities are spin-offs from these smaller pilot-plant studies. The IERL-RTP pilot plant is a cost-effective route to process improvements in scrubbing technology.

The workable mist eliminator washing techniques developed under the 1-MW TVA pilot-plant study are of considerable importance to the industry toward increasing the reliability of slurry scrubbing systems. The results have been confirmed at the larger Shawnee test facility, and mist eliminator performance should be less of a barrier to reliable operation than before.

Although complete results from the Bahco and LG&E lime-limestone programs are still forthcoming, both these activities have considerable potential for contributing to the overall FGD effort. The Bahco technology is directly applicable to smaller size (5-50 MW) industrial boilers, and the LG&E program should be used to improve performance of large systems through application of unsaturated mode operation.

Advancement of double-alkali technology is moving at an accelerated pace using results of the interagency program. The number of double-alkali process applications has begun to increase now that data from the CEA-ADL development work at the Scholz Steam Plant is becoming available. This technology, which offers potential for increasing the reliability of FGD, has been chosen by several utilities. If the results from Scholz can be translated into long-term runs at the LG&E installation, additional impetus will be given to the use of double-alkali scrubbing by utilities.

Unlike lime-limestone and double-alkali technologies, which have received considerable advancement from both EPA- and industry-funded applications, the state of development of regenerable process technology has been largely dependent on efforts supported by EPA. Thus far, regenerable process achievements generally have been more difficult to come by. As can be discerned from the ammonium bisulfate and Cat-Ox programs, the development of this technology has encountered difficulties; however, the long-term potential of producing useful byproducts justifies considerable development efforts in this area. Successful long-term demonstrations of the magnesium oxide, W-L, aqueous carbonate, and citrate processes are important to the acceptance of regenerable FGD technology. The magnesium oxide process is an excellent system for sulfuric acid production and the W-L system can be designed for acid production as well as elemental sulfur. Both of these are first-generation processes. The aqueous carbonate and citrate processes are second-generation processes and their development could open the way to cost-effective elemental sulfur production from power plant stack gases.

Assuming successful completion of the citrate, aqueous carbonate, double-alkali, and W-L/demonstrations now underway, these processes, along with lime, limestone, and MgO, will offer industry at least seven key process alternatives to utilize for SO_2 control. The addition of a gypsum-producing system would also complement the options available.

The support studies funded under the Federal Interagency Program have contributed to the knowledge in some important areas of FGD technology. With many of the new processes requiring reductants for conversion of SO_2 to sulfur and with available supplies of natural gas quite limited, the Battelle study on reductants comes at an important time. The TVA detailed process cost studies have also had an impact on the industry serving as a means to compare process alternatives economically and to supply sufficient generalized equipment and installation costs so that utilities can more accurately estimate their own costs for prospective scrubber systems. The TVA by-product marketing studies should go a long way in helping to inform the industry on the sales approaches that can be used, the most desirable sales outlets, the costs of transportation, and the most promising candidate power plants for FGD byproducts.

The effective transfer of technology from the pilot plants, prototypes, and demonstration projects is essential for widespread successful application of FGD. Thus far, the utilization of some developments has been sluggish; but in time, through a variety of mechanisms, such as reports, industry briefings, and symposiums, the use of developed information should escalate. As a means of expediting the use of developed technology, plans are now under consideration to pursue a more positive applications-oriented technology transfer program involving a higher degree of participation and coordination by EPRI, the utility industry, and FGD system vendors.

CONCLUSIONS

For sulfur oxides control of medium- and high-sulfur fossil fuels, the state of FGD technology is well advanced over competing technologies. With about 120 units of approximately 50,000 MW either operational, under construction, or planned as of March 1977, the experience level of this technology is escalating rapidly.

The development of lime-limestone scrubbing is far ahead of other FGD systems primarily because of information gathered from operational systems and through development sponsored by the Federal interagency program. The Shawnee prototype and the EPA-IERL pilot plant have been effective efforts. The TVA 1-MW pilot plant has also contributed to advancement of technology. If future power plant scrubber systems are designed to take advantage of data already available, improvement in overall reliability, cost, and effectiveness should transpire. Additional work is needed in this area of technology, however, to improve performance, reduce costs, and increase reliability. Better solutions to the problems of sludge disposal are needed, raw material utilization needs improvement, and the initial cost of systems should be reduced.

Double-alkali technology is rapidly coming into its own as a viable means of SO_2 control. The potential advantages of such systems to improve SO_2 removal, sludge characteristics, and operating reliability first need to be confirmed through the full-scale LG&E demonstration, then applied as an alternate to lime-limestone technology. The work thus far has been promising toward confirming these advantages.

The area in which the most work remains to be done is in regenerable process technology. The presently planned demonstrations need to be completed as soon as possible. In addition, further work is needed to confirm the long-term effectiveness and economics of magnesium oxide scrubbing. This technology has already shown promise and the remaining questions revolve primarily around process reliability and cost, marketability of byproducts, and absorbent recycle and losses.

It can be concluded that the support programs under the interagency umbrella have extended the knowledge of the industry by shedding light on a number of problem areas. Studies should be continued in special problem areas, such as byproduct marketing, sodium sulfate disposal, comparative process economics, sludge disposal, and reductants for SO_2 to sulfur.

The technology transfer program has been effective in most areas, but there remains a certain resistance to full utilization of reported technology. Perhaps the deeper involvement of process vendors in such efforts could increase the applications of research results. Efforts in technology transfer need to be continued and, if anything, intensified to make the best use of available information.

In summary, the Federal interagency FGD program is quite broad, has been successful in several areas, but still needs additional work in a number of activities. With many important projects in their earliest stages, FGD developments of considerable interest to the utility and industrial sectors will be forthcoming for quite a while.

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FINE PARTICULATE EMISSIONS CONTROL FROM STATIONARY SOURCES

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INTRODUCTION

Fine particulates are a health hazard because, in contrast to coarse particles, they can bypass the body's respiratory filters and penetrate deep into the lungs.[1,2] Fine particles released into the atmosphere remain airborne for extended periods of time, obstruct light and cause limited visibility typical of air pollution, haze and smog. They have been identified as transport vehicles for gaseous pollutants. The health hazards of fine particulates are intensified by the tendency of metallic materials from high-temperature processes, such as pyrometallurgical and combustion processes, to condense as chemically and catalytically active fine particles. Many toxic and potentially hazardous compounds are also emitted as fine particulate.[1] Particulate matter formed in the atmosphere from chemical reaction and condensation is called secondary. The phenomena associated with the formation and transport of secondary particulate make it difficult to relate atmospheric particulate pollution levels to specific sources. This problem has hampered the development of effective, fine particulate control strategies and the establishment of meaningful fine particulate emission standards. The control of these secondary forms of particulate must be through control of their precursors, and it is generally thought that primary emitted particulate plays an important role in the formation cycle.

Many years will be required to develop a sound data base to quantify the health effects problem of fine particulates. Sufficient information does exist, however, to conclude that fine particulates must be controlled if public health is to be protected.

In order to pursue the goal of developing control technology for fine particulate emissions, the current basic EPA fine particulate program has been divided into six main areas.

1. Characterization and Improvement of Conventional Control Equipment and Assessment of the Collectability of Dusts.
2. Development of Technology for Control of Particulate Emissions from the Combustion of Low Sulfur Coal.
3. New Particulate Control Technology Development.
4. New Idea Identification, Evaluation, and Technology Transfer.
5. High-Temperature and High-pressure Particulate Control.
6. Accelerated Pilot Demonstrations.

Elaboration on each of these program areas will follow in the succeeding discussion.

TECHNICAL AND PROGRAM DISCUSSION

1. Characterization and Improvement of Conventional Control Equipment and Assessment of the Collectability of Dusts

a. Electrostatic Precipitators (ESPs) - The EPA has completed the total characterization of seven ESPs operating on a number of sources ranging from power plants to aluminum plants.[3,4] Data from these tests have clearly shown that ESPs can collect particles of all sizes with high efficiency when dust resistivity is not a problem. Data and theoretical predictions indicate that high dust resistivity limits ESP performance.

EPA has completed work to determine the electrical conduction mechanisms in fly ash at high temperatures (730°F/390°C).[5,6] Work in this area is being extended to low temperatures. One outcome of this work has been the demonstration of sodium as a potential conditioning agent to reduce fly ash resistivity. EPA has evaluated and published reports on conditioning agents such as SO_3 and NH_3.[7,8] Conditioning appears to be a possible solution to retrofit type problems but not for new installations. Conditioning will not be a solution if it causes adverse environmental effects. EPA will conduct further tests to assess the total impact of conditioning. One test has already been completed and preparation for others is currently in progress.

Specially designed charging or precharging sections are a possible means of improving the collection of fine high resistivity particles. A fundamental study and limited pilot plant work on particle charging was begun in FY-74. This work was continued through FY-76 and resulted in a laboratory demonstration of the feasibility of this concept. A pilot scale demonstration will be funded in FY-77.

b. Scrubbers - The Environmental Protection Agency, as a part of this R&D program, has tested approximately ten scrubbers of conventional design on a variety of particulate sources.[9] In general, it can be said that the performance or efficiency of a scrubber drops off rather rapidly as the particle size decreases. It can be said that the efficiency is directly related to the energy consumed by the scrubber.

The broad objective of the fine particle scrubber program is to develop low pressure drop (30-50 cm water pressure drop) scrubber systems capable of collecting at least 90% by mass of particles smaller than 3 microns in diameter. With the exception of two TCA scrubbers, the performance of all conventional and novel scrubbers tested by EPA has been predictable. The TCA scrubbers appear to perform better at the same pressure drop than other scrubbers. Some additional data taken during FY-76 and FY-77 has indicated that the superior performance previously measured on TCA scrubbers is very likely the result of condensation effects with the scrubber system.

The major thrust of EPA's scrubber program has been aimed at developing and demonstrating Flux Force/Condensation (FF/C) scrubbers.[10] In an FF/C scrubber, water vapor is condensed in the scrubber. When the water vapor condenses, additional forces and particle growth contribute to the particle collection process. When the water vapor or steam is "free", FF/C scrubbers are low energy users. However, when water vapor or steam has to be purchased, FF/C scrubbers require additional energy inputs for efficient particle collection. Answers to questions of how much steam is needed and how much is free are major unknowns at present. Answers to both questions are likely to be source specific. Thus, pilot demonstrations on a variety of sources are necessary to provide required data. One pilot demonstration on a secondary metal recovery furnace has been completed. A second pilot demonstration on an iron cupola is underway.

The overall efficiency of a scrubber system is determined by the efficiency of the scrubber and the efficiency of the entrainment separator. Recent field data indicate that in some cases inefficient entrainment separator operation is a major cause of poor fine particle collection by scrubbers. EPA has recently completed a systems study of entrainment separators.[11] In FY-76 the design of these separators for fine particle control was optimized. This design is now ready for demonstration.

c. Fabric Filters - The performance of baghouses has been completely characterized on three sources, two utility type boilers and one industrial boiler.[12,13,14] The data obtained from these tests show that baghouses are relatively good fine particle collectors and their performance is not very sensitive to particle sizes down to at least 0.3 microns. A major advantage of fabric filters is that they will not require increases in size or energy usage for efficient collection of fine particles.

The objectives of the immediate work by EPA in the fabric filtration area are:

(1) Understanding of the filtration process.

(2) Application to and demonstration on priority sources.

(3) Achievement of cost/energy effectiveness.

(4) Development and testing of new filter materials which can extend the applicability of baghouses to a broad spectrum of sources.

d. Assessment of the Collectability of Dust - Actual data on fractional efficiency of conventional particulate collectors is sparse. Actual operating data for the optimization of collection efficiency and cost is not readily available. Design of control equipment is presently based on projections from historical data which has been developed by manufacturers for their own devices and is proprietary. This information is not standardized and cannot be extrapolated to other devices. On-site testing prior to selection is seldom attempted and the possibility of alternative devices is poorly defined.

Several mobile collectors which can be easily transported from source to source and tested have been constructed. A mobile scrubber, fabric filter and ESP are completed and are in use. The ESP was completed in late 1976 and was put into operation. The fabric filter and scrubber have been in operation for several years. These mobile units are highly versatile and will be used to investigate the applicability of these control methods to the control of fine particulate emitted from a wide range of sources. The relative capabilities and limitations of these control devices will be evaluated and documented. This information, supplemented by data from other EPA particulate programs, will permit selection by equipment users of collection systems that are technically and economically optimum for specific applications. Operation of the mobile units will be coordinated with other EPA laboratories and regions to provide, when possible, field data on specific control sources.

The mobile fabric filter unit has been operated on effluents from a brass and bronze foundry, a hot mix asphalt plant, a coal-fired boiler, a lime kiln and a pulp mill recovery boiler. It has also been used to determine the performance of a fabric filter on the air emissions from a cyclone collector used on the St. Louis Refuse Processing Plant. The filter unit is now operating on site to obtain preliminary data for an EPA funded demonstration of a fabric filter on a 350 megawatt boiler burning low sulfur coal. The mobile wet scrubber unit has been operated on a coal fired power plant, a lime kiln in a pulp and paper mill and on a gray iron foundry. The mobile electrostatic precipitator is operating in the field for the first time on an industrial boiler burning a mixture of coal and pelletized refuse. This unit will be taken to a field site this month to evaluate the effects of sodium conditioning on a low sulfur western coal.

2. Development of Technology for Control of Particulate Emissions from the Combustion of Low Sulfur Coal

One method of reducing the sulfur emissions from coal-fired power plants is to switch from high sulfur coal to low sulfur coal. Several utilities and EPA envision such fuel switching as a means of achieving acceptable air quality without the need for installing sulfur dioxide (SO_2) scrubbers. At first glance coal switching appears to be a near optimum method of achieving acceptable air quality without the need for installing SO_2 scrubbers. The need for scrubbers and their associated potential water pollution problem is eliminated. As a result of the attractiveness of low sulfur coal, many utilities are considering either switching to low sulfur coals or cleaning high sulfur coals to meet SO_2 requirements. Such coal switching is likely to greatly increase the particulate emissions from coal-fired boilers since low sulfur coal generally has high resistivity at normal ESP operating temperatures. This can cause serious problems in effective ESP operation.

The objective of the low sulfur coal particulate emission control program is to develop particulate control technology to insure that use of low sulfur coal to meet SO_2 standards does not result in violation of particulate standards. Existing options for control of particulate from combustion of low sulfur coals will be assessed. Development and demonstration of improved electrostatic precipitators will be accomplished as will demonstration of fabric filters. The usefulness and environmental impact of fuel and flue gas additives for improving collectibility of particulate from low sulfur fuels will be determined. Promising conditioning agents will be demonstrated. The impact of coal cleaning on particulate collectibility will be determined and methods for dealing with any problems due to coal cleaning will be developed.

EPA in FY-77 is funding a demonstration test of a baghouse installed on a 350 megawatt boiler burning a low sulfur coal. An option is included in this program to use the baghouse as a dry collector of SO_x. Demonstration of sodium conditioning on a small coal-fired boiler will be funded in FY-77. Ongoing pilot plant work on the EPA developed fine particle/high resistivity ESP system will allow design of a semi-commercial scale unit to begin in FY-77.

3. New Particulate Control Technology Development

This is the program area which has become known as "New Concepts." As the requirement to collect finer and finer particulate has developed, the cost of conventional control (ESPs, fabric filters, scrubbers) has risen. Since many important collection mechanisms become far less effective on particles less than 1 micron in diameter, conventional devices (except for fabric filters) have become larger or require more energy and thus are more expensive. The objective of new concepts R&D is to develop new mechanisms or new combinations of well studied mechanisms in order to achieve cost effective control of fine particulate. New concepts include any new technology which has not been reduced to practice and may or may not have been previously studied.

Mechanisms utilized by scrubbers and fabric filters are impaction, interception, and diffusion and by ESPs are field and diffusion charging. This combination of mechanisms gives rise to a minimum in efficiency at the 0.2 to 0.5 micron range for conventional devices. Under optimum conditions, this minimum may be greater than 90% for scrubbers and ESPs and greater than 99% for fabric filters. However, under other conditions such as high temperature, high ash resistivity, sticky particulate, and corrosive or explosive flue gases, new concepts specific to a problem will have an advantage.

Most work to date has been directed toward combining electrostatic removal mechanisms with scrubbing or filtration mechanisms. The first area to be developed was charged droplet scrubbing, with a feasibility study at M.I.T. and a pilot demonstration at TRW on a Kaiser coke oven.[15] Electrostatics and filtration are being studied at both Battelle Northwest and Carnegie-Mellon; the former with bed filters, the latter with baghouses. At least two new concepts, a ceramic membrane filter and a magnetic fiber bed, are oriented toward cleanup of high temperature gases (1000-2000°F/500-1100°C). Other new concepts being studied are foam scrubbing and pleated cartridge filters of a novel material. Most new concept work is in the early stages of development; however, the TRW charged droplet scrubber was demonstrated successfully at pilot scale on a coke oven and the magnetic separator is currently undergoing laboratory pilot scale tests. EPA has thus far evaluated about 40 new concepts. Of these 10 have been selected for funding.

EPA has during the past year moved into the area of developing device-oriented technology which will have an impact on fugitive dust emissions from stationary sources. This program was initiated after an OAQPS report showed that in the near future fugitive dust emissions from stationary sources will be a major uncontrolled source of suspended particulate which will impact on the ability to meet ambient air quality standards.

4. New Idea Identification, Evaluation, and Technology Transfer

This area is called for convenience the "Novel Devices" area. It includes, in addition to Novel Device evaluation and testing, a program aimed at soliciting, stimulating, and identifying new ideas for fine particulate control.

As a part of this last objective, EPA has planned and sponsored to date six symposia and two seminars aimed at fine particle control. In 1976, two conferences were sponsored on particulate collection problems in converting to low sulfur coals. The Second Fine Particle Scrubber Symposium was held in New Orleans in May 1977. A Conference on Particulate Collection Problems in the Use of Electrostatic Precipitators in the Metallurgical Industry is scheduled to be held in Denver in June 1977 and a Fabric Filter Symposium is scheduled to be held in Tucson in December 1977. A symposium jointly sponsored by EPA and ERDA on High Temperature/High Pressure Particulate Control is scheduled for September 1977. EPA also has completed a literature search aimed at identifying new technology in foreign countries (Japan, Canada, Russia, and Australia).

Devices or systems based on new collection principles or on radical redesign of conventional collectors are sometimes offered by private developers. Under this program area all such novel devices will be reviewed and if promising will be evaluated for performance and related cost. It is intended that those showing promise of high efficiency fine particle collection at reasonable cost, if necessary, be further developed or demonstrated.

More than 40 novel particulate devices have been identified. About half of these have been of sufficient interest to justify a technical evaluation. To date 11 devices have been either field or laboratory tested:

Braxton-Sonic Agglomerator
Lone Star Steel - Steam Hydro Scrubber
R. P. Industries - Dynactor Scrubber
Aronetrics - Two-Phase Wet Scrubber
Purity Corporation - Pentapure Impinger
Entoleter - Centrifield Scrubber
Johns-Manville - CHEAF
Rexnord - Granular Bed Filter
Air Pollution Systems - Electrostatic Scrubber
Air Pollution Systems - Electrotube Scrubber
Century Industrial Products - FRP-100 Scrubber

Of the devices tested, the Lone Star Steel Scrubber gave the highest efficiency on fine particulate, but it is also a high energy user.[16] It can use waste energy, when available. The Aronetics Scrubber is similar to the Lone Star, but was not as efficient. In a field test the CHEAF had an overall mass efficiency of 95% but maintained the efficiency down to about 0.3 microns. The APS electrostatic scrubber was equal in fractional collection efficiency to a venturi scrubber using 2-1/2 times as much power. The APS Electrotube, which is similar to a wet-wall ESP, gave some very high collection efficiencies on fine particles—as high as 98.9% on 0.5 micron particles. This performance is similar to that which can be achieved in small wet ESPs with the same ratio of plate area to volumetric flow rate as the Electrotube unit tested. None of the other devices tested showed significant improvement in fine particle collection over a conventional scrubber of equivalent power requirements. Proposals have been received and evaluated for demonstration at full scale of a promising novel device. A demonstration will be funded in FY-77.

5. High-Temperature/High-Pressure Particulate Control

This program area was added in FY-75 as a result of the critical particulate and fine particulate collection problems associated with the advanced energy processes. The broad objective of the high-temperature, high-pressure program is to develop the particulate collection devices which are needed to ensure the environmental acceptability of advanced energy processes. However, because the requirements of such energy processes are as yet unknown, EPA has established a near term objective of developing the fundamental information on the mechanics of aerosols at high temperatures and pressures necessary to determine the most logical path for high-temperature, high-pressure particulate collection research and development.

The state-of-the-art of high-temperature, high-pressure particulate collection is very unclear. There is no clear specification of the degree of particulate collection needed by advanced energy processes. Also, there are no reliable data for the performance of the particulate collection devices proposed by various companies; e.g., granular bed filters and high pressure-drop cyclones. There are few data, correlations, or verified theories that can be used to predict the performance of particulate collection devices at elevated temperatures and pressures.[17]

The evaluation and development of particulate control devices has been a strong EPA program and includes the early stages of high-temperature, high-pressure particulate control development. In FY-74, funds were allocated to develop high-temperature, high-pressure (10 atm and 1700°F) ESPs. Conventional ESPs operate at 300-800°F. This work is being carried out by Research Cottrell. An advanced mechanisms study is being conducted by Air Pollution Technology (APT). As a result, APT will make recommendations as to which mechanisms appear to be the most effective for high-temperature, high-pressure particulate removal. APT, in addition to the mechanisms study, has a dry scrubber contract. This contract involves a device which allows large spheres to go into the venturi section of a scrubber where the spheres capture particles as drops would in an ordinary scrubber. Aerotherm has a contract to test metallic and ceramic fabric bag filters and Westinghouse has a contract to look at ceramic membranes for particulate control. A granular bed systems study also by APT includes field tests of two working granular bed filters. EPA, as part of the advanced energy processes program, is looking at granular bed filters

(Exxon miniplant) and high pressure-drop cyclones (Consolidation Coal). As part of the novel device program previously mentioned, EPA is attempting to evaluate either or both the Rexnord or Combustion Power granular bed filters. Most of this work is still in progress and no definitive results are expected before early 1978. However, the basic mechanisms study has been completed.

6. Accelerated Pilot Demonstrations

Little attention will be given to this program area since it was covered in each of the preceding sections. Suffice it to say that EPA has currently funded five pilot scale demonstrations and should fund at least three demonstrations in FY-77.

CONCLUSIONS

It can be concluded that adequate control of emitted submicron particulate matter is presently possible but not broadly applicable to a wide variety of sources including utility sources.

Highly efficient electrostatic precipitators, installed on sources whose dust properties are such that they lend themselves to electrostatic collection, can currently be effective in controlling fine particles. Additional R&D is needed, however, to improve the performance of precipitators on particulate whose electrical resistivity is too high and on particulate in the size range of 0.1 to 1.0 microns. This size range is quite important since it is the most optically active and causes atmospheric haze and thus visibility problems. Techniques which either enhance charging or selectively charge fine particles are currently being sought by R&D programs of EPA's Industrial Environmental Research Laboratory in North Carolina (IERL-RTP).

Conventional scrubbers are not very efficient collectors of fine particles. Current R&D efforts to improve scrubbers are directed toward more efficient utilization of the energy applied to a scrubber system, and toward taking increased advantage of condensation and other physical phenomena which affect to some degree the performance of all scrubbers. One successful demonstration of a condensation scrubber was completed in 1976 and a second demonstration is underway.

Fabric filters are taking on increased importance with respect to control of particulate emissions from utility boilers burning low sulfur coal. EPA will demonstrate a large fabric filter on such a boiler in 1978.

The state-of-the-art and the requirements of high-temperature and pressure particulate collection associated with the advanced energy processes is very unclear. Also, there are no reliable data for the performance of the particulate collection devices proposed for the various advanced processes, and there are few correlations or verified theories which can be used to predict performance at elevated temperatures and pressures. Much research and development remains to be done to ensure the environmental acceptability of these new processes.

So far only five novel devices have been tested and found to be good collectors of fine particulate. Many more device tests are planned, and a number of new and different concepts, such as ceramic membrane filters, electrostatic fabric filters, and foam scrubbers, are being investigated on a laboratory scale. One new concept, the charged droplet, has been demonstrated to be a good collector of fine particles. It is hoped that several of the devices and concepts currently under consideration by EPA's IERL-RTP will ultimately result in the demonstration of new and economically attractive processes for the control of all emitted particulate matter.

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STATIONARY SOURCE CONTROL TECHNOLOGY FOR NO_x

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INTRODUCTION

Nitrogen oxides (NO_x), principally nitric oxide (NO) and nitrogen dioxide (NO_2), have been identified among the atmospheric pollutants having the greatest potential for adverse effects on human health and welfare. Man-made emission contributions lead to NO_x concentrations in urban atmospheres of 10 to 100 times higher than those from natural sources in nonurban areas. Fuel combustion in a wide variety of equipment contributes about 99% of technology-associated NO_x emissions. For most equipment types about 95% of the NO_x is emitted as NO and 5%, as NO_2. In the atmosphere, the NO_x enter into complex photochemical reactions with hydrocarbons and sulfur oxides and result in the formation of undesirable secondary species, with a shift of residual NO to NO_2. The adverse effects of NO_2 on humans, animals, vegetation, and exposed materials, and similar adverse effects of the other pollutants were among the factors which led to passage of the Clean Air Act of 1970. With respect to NO_x, this Act empowered the EPA: (1) to establish primary and secondary National Ambient Air Quality Standards (NAAQS) for NO_2; (2) to require a 90% reduction in NO_x emissions from light duty motor vehicles; (3) to establish New Source Performance Standards (NSPS) for stationary sources; (4) to set up mechanisms to assure compliance and enforcement; and (5) to provide research, development and demonstrations of new and improved, commercially viable methods for the prevention and control of pollution from the combustion of fuels.

NO_x emissions in the U.S. in 1974 from anthropogenic sources were about 23 metric tons per year. Of this amount 46.1% was estimated to come from mobile sources, 50.4% from fuel combustion in stationary sources, and the remainder from miscellaneous sources. The major control strategy at that time was based on the 90% reduction of emissions from mobile sources to 0.4 grams of NO_2 per mile (0.25 mg NO_2 per metre) and on the moderate reduction of NO_x emissions from stationary sources by application of the NSPS. During the ensuing years, the development of cost-effective NO_x control techniques to achieve the initial automotive emission goals met with difficulties not yet overcome. This factor along with the projected changes in energy and fuel utilization have shown the need for revised NO_x strategies to assure achieving and maintaining NAAQS for NO_x. Currently, emphasis is being placed on more vigorous NO_x control for stationary sources; a Maximum Stationary Source Technology (MSST) program for NO_x control technology development has been recommended.

Several approaches to the control of NO_x emissions from stationary sources under consideration in the Industrial Environmental Research Laboratory-Research Triangle Park (IERL-RTP) are:

(1) Combustion modification (CM), to minimize NO_x formation, which has the potential for achieving substantial NO_x control for a wide variety of combustion sources using both conventional and alternate fuels in a cost effective manner.

(2) Flue gas treatment (FGT), or removal of NO_x from combustion or process effluent gases, which may be used singly or, more likely, as a supplement to combustion modification where very low NO_x levels are required.

Separate programs were initiated in IERL-RTP predecessor organizations prior to 1970 to investigate CMs for conventional and alternate fuels, and FGT. This paper provides a two-part report on the status of the CM and FGT elements of the NO_x program.

PART I. COMBUSTION MODIFICATION (CM)

The need for better control technology for NO_x from stationary combustion sources was identified as early as 1967 and led to a systems study of NO_x control methods for stationary sources. This study concluded in 1969 that CMs would be the most cost-effective techniques for reducing NO_x emissions from the sources in the near-term.

Consequently, the CM Program was developed. Because of limited funding and the large number of combinations of combustion equipment/fuel categories comprising the entire stationary combustion source spectrum, the initial program considered the highest priority sources from an NO_x emissions point-of-view. Based on available fuel utilization and NO_x emissions data, the early program emphasis was placed on developing controls for those utility boilers, industrial boilers, and commercial heating systems which burned the dirtier fuels (e.g., coal and residual fuel oils). The pre-1975 phase of the program was based on: (1) field testing of boilers at baseline and modified operating conditions; (2) application of state-of-the-art technology with minor hardware modification; and (3) fundamental and small pilot scale experimental studies to identify promising technology approaches.

More recently, based on improved understanding of NO_x formation and of potential methods for control, coupled with greater funding commitments, a more comprehensive CM Program for NO_x control is in progress. Based on the EPA's present strategy of providing MSST to assure maximum achievement of NO_x environmental goals, the current CM Program is a broadly structured program which provides both for the development of CM technology for major stationary combustion sources and for the environmental assessment of the application of these technologies. The program's technology development activities are grouped according to emphasis as follows: (1) utility and large industrial boilers, (2) small industrial, commercial and residential systems, (3) industrial process combustion and afterburners, (4) stationary engines, (5) advanced processes, and (6) fundamental combustion research. Similarly, the environmental assessment activities are sub-divided into: (7) environmental assessment, and (8) applications testing.

Technical Discussion

NO_x Formation and Techniques for Its Control. Two predominant mechanisms account for the formation of NO_x during combustion, as indicated by the widely used terminology, *thermal NO_x* and *fuel NO_x*. Thermal NO_x is formed by the fixation of molecular nitrogen present in the combustion air though a series of reactions which are exponentially dependent on temperature and are slightly dependent on oxygen availability. Fuel NO_x is formed by oxidation of the organic nitrogen compounds contained in some fuels through reactions which are relatively independent of temperature and are strongly influenced by oxygen availability. For any fuels containing bound nitrogen both mechanisms contribute to the total NO_x formation.

Working from this knowledge of the NO_x formation chemistry, a number of control technology approaches have been formulated. Techniques for control of thermal NO_x are based on reducing the peak temperatures in the combustion zone, and include staged combustion, low excess air, flue gas recirculation, and water injection. Techniques for control of fuel NO_x are based on reduction of oxygen availability in the combustion zone, and include low excess air operation and staged combustion. In addition, pilot scale combustion studies have shown that changes in burner design can also significantly reduce the formation of both thermal and fuel NO_x by aerodynamically influencing local recirculation rates and/or oxygen availability in the flame. The optimum level of control may require a combination of these approaches. Although the control techniques have good potential in experimental systems and on some practical equipment, the optimum levels achievable have yet to be established and are the subject of this program. Based on current information, emissions of other pollutants (e.g., carbon monoxide and other products of incomplete combustion) can be maintained at low levels while achieving significant NO_x reduction by proper system design. Many of the NO_x control techniques, such as low excess air operation, even offer potential for increases of system efficiency. Based on limited experience with long term service it appears that operability problems, including fireside corrosion, can be avoided by proper design.

Status of Technology R&D and Environmental Assessment. The above principles have formed the basis for the development of CM techniques, to be applied to the wide variety of combustion sources. The technical status of the overall program, which is made up of approximately 30 separate projects, is discussed briefly below to highlight progress of key portions of the effort.

That part of the program aimed at CM technology development for *utility and large industrial boilers* has its primary emphasis on the development and demonstration of low-emission, high-efficiency, cost-effective techniques for NO_x control of coal-fired systems. Although the major effort has continued on the investigation of staged combustion technology for application to several classes of utility boilers, work is also underway on improved low-emission pulverized coal burners which should be applicable to utility boilers. In addition, investigations are evaluating combustor design concepts for advanced systems firing low Btu gases with acceptable levels of NO_x emissions.

Staged combustion technology has been tested on several tangentially fired utility boilers greater than 400 MW, burning western coals, to determine if this approach would be as effective for coal of this rank as for the eastern bituminous coals. These tests have shown NO_x emission levels of about 0.45 lb per 10^6 Btu* under optimized conditions of overfire air operation. There was no significant increase in waterwall (fireside) corrosion rates during optimized operation as determined by a 30-day corrosion study utilizing corrosion probes.

Earlier results of staged combustion when applied to wall-fired boilers showed the potential for achieving NO_x levels in the range of 30-50% below the present NSPS of 0.7 lb NO_x per 10^6 Btu. Limited test data showed that implementation of these control techniques have the potential for increased fireside tubewall corrosion. Consequently, a program was planned to carefully assess the long-term performance of this control technique and to quantify in detail the tubewall corrosion associated with optimum low-NO_x operation, but because of limited availability of funds, it has not been possible to implement the entire effort at this time.

Improved low emission, high efficiency burners for application both to utility and industrial boilers are under scale-up development. This burner development effort, discussed to a greater extent later, may have the potential for reducing NO_x emissions to the range of 0.2-0.3 lb $NO_x/10^6$ BTU by 1985.

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*This may be multiplied by 430 to convert to the metric equivalent in ng/J.

The portion of the program dealing with small industrial, commercial and residential systems provides for development and/or field evaluation of emission control technology. Emphasis is on: (1) residual oil fired package boilers; (2) distillate oil fired residential furnaces; and (3) stoker coal fired boilers. The technical progress in each of these areas is summarized below.

Laboratory and field studies have shown that staged combustion is capable of reducing NO_x emissions from residual oil fired package boilers by up to 50%; however, significant modification is required. Therefore, studies of residual oil burner design were conducted and showed that similar emission levels could be achieved by proper aerodynamic control of air and fuel mixing. The limit of achievable NO_x control is imposed by the onset of excessive carbon particulate formation. A study is now in progress to identify fuel and atomizer properties that are favorable for suppressing this particulate formation, thereby allowing more effective NO_x control.

The residential oil furnace program has progressed from a concept originated from EPA in-house studies to an integrated design of a low emission, high efficiency furnace. EPA in-house testing of residential oil burners showed that proper design of the burner could not only reduce NO_x, but also achieve low carbonaceous emissions at low excess air. The development contracts that followed identified an optimum burner design and design criteria for burner and firebox matching. These were developed and incorporated into a design of an integrated furnace. The prototype furnace tests showed over 70% reduction of NO_x relative to conventional furnaces and the potential for significant energy savings. The pre-production furnace design has been constructed and will be tested in the field.

Stoker coal fired boiler studies have included both laboratory and feild work. The emisions from small underfeed stokers have been measure for a range of coals, including processed smokeless ones. An experimental study is now in progress to develop technology for large spreader stokers. In a field study, EPA has evaluated the use of low-sulfur western coal in ten industrial boilers of which eight were stoker fired. The study indicated that switching from an eastern high sulfur bituminous to a western low sulfur coal is feasible with a minimal operational impact, although some problems are documented. Emissions of SO_x and NO_x were generally reduced.

In the stationary engines area, work is underway to develop control technology for large gas turbines and reciprocating internal combustion engines. A major contractor is focusing on dry CM approaches for gas turbines to achieve R&D goals of 50 ppm NO_x (at 15% O_2) for clean fuels and of 100 ppm, for fuel containing up to 0.5% bound nitrogen. These goals represent a 75% reduction from uncontrolled NO_x emissions. The experimental effort under this contract has proved encouraging in that limited testing of several combustor configurations has yielded emissions data meeting the goals. Another major contract is under negotiation for the development of control technology applicable to large-bore reciprocating engines.

The part of the program aimed at technology development for industrial process combustion equipment and afterburners is one of the lower priority areas, with emphasis placed on better definition of the potential problems. The activities include an environmental assessment of afterburners and a survey of industrial process combustion equipment.

The advanced processes part of the program provides for the initial development of CM technology with the potential for very low emissions. The R&D areas include: (1) low emission, high efficiency burners for fossil fuel combustion; (2) improved concepts of staged combustion; (3) use of low and high nitrogen alternate fuels; and (4) catalytic combustion. The technical progress in each of these areas is summarized below.

Pilot scale studies have shown that burner design modification affecting fuel/air mixing history has the potential for reducing NO_x emissions to below 0.2 lb of NO_x (as NO_2) per 10^6 Btu while maintaining flame shape and high carbon combustion efficiency. A study is in progress to derive experimental scaling criteria for practical size coal and oil burners. In addition, a small multiple burner pilot scale furnace is being used to determine criteria for optimizing staged combustion for NO_x control from pulverized coal. It has been shown that a long residence time rich primary can reduce NO_x levels to below 0.2 lb NO_x per 10^6 Btu fired.

With combustion of alternate fuels free of bound nitrogen, e.g., low Btu gas and methanol, NO_x emissions are generally lower that for fossil fuels and thermal NO_x control techniques are effective. Fuels containing significant amounts of nitrogen are currently being studied.

An initial assessment of catalytic combustion indicated the potential for very low NO_x emissions (i.e., below 10 ppm). Experimental work is in progress to identify catalysts capable of high temperature operation, i.e., 2800°F (1810K), and to define combustion system configurations capable of both low emissions and high thermal efficiency. One catalyst system capable of operating at 2700°F (1755K) with emissions of CO, NO_x and HC below 10 ppm has been identified.

Fundamental combustion research studies provide the basic understanding of the phenomena responsible for pollutant formation and destruction in the combustion process. These studies emphasize the chemistry and aerodynamic aspects of the combustion processes, and are used to guide the development and optimization of new technology.

Special attention is being directed at fuel nitrogen reactions and at the formation of primary and secondary pollutants since these species may be strongly affected by changes in the combustion process.

Although in earlier years there were many small fundamental studies, a newly developed large contract has been awarded. It is aimed at applying fundamental research results in the definition of optimum combustion control for all systems. Future fundamental studies will be consolidated under this contract.

Results of major fundamental research efforts are discussed below. Studies of fuel decomposition have identified the principal nitrogen species evolved during pyrolysis of a fuel and have also shown that the fraction of nitrogen evolved is strongly dependent on temperature. These two outputs have a direct relation to low NO_x burner experiments for nitrogen containing fuels. A study of the mechanism and kinetics of NO_x formation under normal and modified combustion conditions gave significant insight into the kinetics responsible for thermal NO_x formation under fuel rich and near stoichiometric conditions. Aerodynamic phenomena in the control of pollutants from gaseous and liquid fuel fired combustors have been evaluated experimentally. Among the more significant findings in this study was the fact that the intensity of the turbulent fluctuations in the early flow fields had a major effect on the local fuel/air ratio.

Two theoretical studies have examined the possibility of formation of (1) PCB's and (2) primary nitrates, sulfates, and acid aerosols in the combustion process. Fundamental study of NO_x, nitrate, and sulfate in laboratory flames is also in progress.

The program also includes development and use of numerical analytical procedures to be used in interpretation of experimental results. Recent developments of codes capable of handling not only complex chemical kinetics but also specie diffusion offer strong potential for use in analyzing flat flame burner data. Aerodynamic models for describing the air/fuel mixing processes of turbulent diffusion flames are also under development; however, several problems remain to be overcome.

A key part of the program is the environmental assessment of the NO_x CM technologies. This effort, being performed by a major contractor, provides for assessment of the multimedia environmental impact of the application of various state-of-the-art (existing) and emerging combustion control techniques to the major combustion sources. The control technologies will be evaluated and compared taking into account such factors as pollutant reduction, process efficiency, system operation, and costs. In addition, systems analyses will be performed to provide comparisons of the effect and adequacy of control technologies or combinations of technologies when applied under various scenarios representing alternate control options or strategies for achieving acceptably low ambient pollutant levels on a local, regional or national basis. A draft report, covering a preliminary environmental assessment of the application of CM technology, lays the groundwork for the entire environmental assessment contract.

Applications testing, usually performed as characterization studies on combustion sources under field operating conditions, is being performed for stationary sources including boilers and industrial combustion equipment. The objectives are: (1) to accurately determine the levels of emissions without controls (baseline) and the levels achievable through the use of optimized operating conditions, or the application of state-of-the-art control technology requiring relatively minor hardware changes; and (2) to determine the effect of these CMs on equipment performance.

Field tests of coal-fired utility boilers have resulted in NO_x reductions of 30 to 50% without apparent adverse side-effects. Tests are being performed to determine the effect on tubewall corrosion rates of the reducing atmosphere created in the lower furnance zone when firing coal with staged combustion. A similar field study of coal, oil, and gas-fired industrial boilers characterized trace specie emissions and showed that NO_x emissions were reduced by up to 47%. Another field study is being performed to determine the applicability for industrial process equipment (kilns, process heaters, etc.) of CMs that have been used successfully for boilers. The degree of effectiveness varies widely depending on the type of equipment and the fuel used. The results of the field test studies are used to prepare design and operating guidelines for manufacturers and users. Based on utility boiler data a model is being developed to indicate design modifications to minimize NO_x while maintaining low emissions of other pollutants, high efficiency, and stable combustion.

Program Discussion

Summary of Major Accomplishments. Significant accomplishments during the past years have resulted primarily from the technology development and applications testing activities. Particularly, progress in the efforts devoted to utility, industrial and commercial boilers, and residential heaters and those based on advanced processes has been most encouraging. Selected accomplishments can be summarized as follows:

(1) Utility boiler testing of new tangentially coal-fired units designed with overfire air systems for staged combustion has shown that NO_x levels as low as 0.45 lb per 10^6 Btu can be achieved with no apparent adverse side effects. Meanwhile, work is underway to assess in detail the effect of CM techniques on fireside watertube corrosion for two wall-coal-fired utility boilers. Scale-up development of an optimum low-NO_x pulverized coal burner for application to utility and large industrial boilers is progressing on

schedule and should lead to testing of a 125×10^6 Btu/hr (36.6 MW_t) burner in FY78. Based on earlier pilot scale studies of a burner of 9×10^6 Btu/hr (2.635 MW_t) capacity, it appears a practical burner with a potential for reducing NO_x emissions to approximately 0.2 lb per 10^6 Btu should be available for commercialization by FY81.

(2) The residual oil burner concept for packaged boilers has been developed and has achieved NO_x reductions of 65 to 70% for three fuel oils with fuel nitrogen ranging from 0.2 to 0.7%. The limit of NO_x control is imposed by the onset of unacceptable levels of carbon particulate formation. Both fuel properties and atomizer design appear to play an important role, and these factors are currently being investigated further.

(3) A prototype oil-fired residential furnace, based on experimentally defined burner-firebox matching criteria, was successfully tested. The system maintained outstanding performance with low excess air operation and achieved a 70% reduction in NO_x relative to current practice with no increase in CO, HC, or smoke.

(4) Recent tests of advanced staged combustion practices, when applied to coal combustion under carefully controlled conditions in a highly versatile pilot scale experimental combustor, have shown outstanding NO_x reductions. Under conditions of fuel-rich first stage stoichiometry (0.85) and long first stage residence time (4 to 5 seconds) NO_x levels as low as 79 ppm (corrected to zero % O_2) were measured. This corresponds to a NO_x reduction of 90% from normal baseline conditions.

(5) The catalytic combustion project offers promise of clean fuel combustion with very low emission levels (i.e., < 10 ppm) of NO_x, CO, HC, etc. One catalyst system, which has undergone extensive performance testing in the screening studies, has operated at 2700°F (1755K) without degradation of catalyst performance.

These and other results coming from the CM program are encouraging since they provide a basis for control technology which can lead to significant reductions in combustion-generated emissions from some sources over the long term (1985-1990). Catalytic combustion of essentially nitrogen-free fuels offers the potential for NO_x to be controlled to levels of 10 ppm or less. Direct combustion of clean fuels containing no bound nitrogen (e.g., methanol), although less effective, may reduce NO_x emissions to below 50 ppm. Refinements of CM techniques and improved burner configurations, based on recent experimental evidence, offer the potential for practical attainment of emission levels of 100-150 ppm for the direct firing of pulverized coal. These promising results provide an impetus for continued development and practical demonstrations of these combustion techniques to solve any remaining associated problems and encourage their early commercialization.

Technology Transfer. The information and data produced in this program have sparked a great amount of interest from a wide range of users. These have included a number of other groups within EPA, state and local regulatory agencies, ERDA FEA, the National Academy of Science, NIOSH, various environmental groups, many parts of the industrial sector (both equipment manufacturers and potential users of the technology), and the general public. Although the information is thoroughly documented in major project reports (see Bibliography), it has become apparent that other means were necessary to better transmit the highlights and key results on a timely basis to a wider range of users.

During the past year, the "Proceedings of the Stationary Source Combustion Symposium" was published. This report contains more than 30 technical papers relating to NO_x control which were presented at a meeting in September 1975. Another similar symposium has been planned for August 29 - September 2, 1977, at which the updated status and results of IERL-RTP combustion control projects will be presented.

A bulletin, "NO_x Control Review," is being distributed on a quarterly schedule to about 2000 addressees. This provides current information on advances in NO_x control strategies, regulations, technology R&D, and applications. It presents information concerning activities of the private sector and of government and, whenever possible, includes news of significant foreign efforts.

A pamphlet, "Get the Most from Your Heating Oil Dollars - Servicing Cuts Costs and Pollution," has been distributed to homeowners across the U.S. It is designed to pass along important practical information, based on earlier field tests of residential heating systems, which should lead to improved energy conservation and emissions reduction for homeowners heating with oil. Pamphlets or guideline manuals are planned for: (1) gas-fired residential furnaces, (2) residential and commercial space heating, (3) industrial boilers, and (4) utility boilers.

PART II. FLUE GAS TREATMENT (FGT)

A second major element of EPA's activities to develop NO_x control technology is the FGT program. This program has received a relatively low level of funding since it has not conclusively been determined that higher NO_x removal efficiencies than those achievable by CM techniques will be required in order to achieve and maintain the current and projected NAAQS. However, due to uncertainties surrounding the overall NO_x problem, the program is proceeding with a small scale experimental program in parallel with control strategy and technology assessment work. Thus, the basic foundation will be in place if the technology is required and acceleration of the development program is necessary.

The EPA FGT program has been directed toward enhancing development of the technology and toward determining if and when the technology will be needed in the U.S. The Japanese, due to their very stringent NO_x regulations, have progressed to the point of commercial application of FGT technology on gas- and oil-fired sources. In addition, activities are underway to evaluate the technology for application to flue gas from coal-fired sources. EPA is investigating the Japanese technology for potential application to the U.S. coal-fired situation to save both development time and money.

Technical Discussion

The objective of the FGT program is to provide highly efficient NO_x and NO_x/SO_x control technology for application to utility and large industrial combustion sources in an environmentally sound, energy efficient, and economical manner. FGT processes can generally be classified in two categories: dry processes and wet processes. The developmental progress in these categories is discussed below.

Dry Processes. Selective catalytic reduction (SCR) using ammonia is the most developed and most promising FGT process. Two EPA sponsored projects investigating SCR have recently been completed. The performance, reliability, and practicability of a SCR system was demonstrated on a 1.5 MW pilot plant using a platinum catalyst. The results indicated satisfactory operation on gas-firing with NO_x removal efficiencies of 85-90%. Operation on oil-firing indicated that platinum and other noble metal catalysts were not suitable for flue gas containing SO_2. In another project, various non-noble metal catalysts were laboratory-tested to determine the optimum catalyst composition for reducing NOx concentrations in flue gas containing SO_2; NO_x removal efficiencies up to 99% were measured.

In Japan, numerous SCR commercial scale plants are being operated to remove NO_x from gas- and oil-fired flue gas. In addition, a commercial scale application is being planned for startup in 1980 on a coal-fired facility. NO_x removal efficiencies in excess of 90% are typical. Through improvements in reactor design, catalysts, and process control, substantial progress has been made in avoiding the early problems with SCR systems such as catalyst plugging, catalyst poisoning, and corrosion.

Wet Processes. The chemistry for wet processes is complex and undesirable by-products are often generated. The wet processes are less developed than dry processes and show higher projected capital and operating costs. However, many wet processes have the capability for simultaneous removal of SO_2 and NO_x; therefore, they are receiving considerable developmental attention.

The most promising wet processes can be classified in two types: oxidation-reduction processes and reduction processes. Oxidation-reduction processes utilize a gas phase oxidant to convert NO to NO_2. The NO_2 is then reduced to nitrogen by reaction with sulfite ions formed from the SO_2 absorption step. In the reduction process, NO is absorbed with SO_2 in a liquid containing a ferrous ion. Usually a chelating compound is added to promote the reduction of NO to nitrogen.

In a recently completed study, sponsored by EPA, the contractor investigated the energy and economic requirements for the oxidation of NO to NO_2 using ozone as the oxidant. The results indicated that wet processes utilizing ozone will be very expensive for NO_x removal only, unless there is significant improvement in ozone generation technology. However, the energy and economic impact may be more acceptable for simultaneous removal of NO_x and SO_x than the sequential installation of SO_2 and NO_x FGT control equipment.

In Japan, the wet processes are generally being evaluated on the pilot plant scale. SO_2 and NO_x removal efficiencies in excess of 95% and 80%, respectively, are typical. Some processes are sufficiently developed to be offered for commercial scale application.

Control Strategy/Technology Assessments. EPA is sponsoring the publication of a series of reports on the status of NO_x and NO_x/SO_x abatement technologies in Japan. In addition, TVA will perform economic assessments of the most promising FGT processes in a project sponsored by EPA and EPRI.

Other control strategy and technology assessment work is focused on determining if and when FGT technology will be needed. Preliminary results of a dispersion modeling study of Chicago indicate that large combustion sources do not make a significant contribution to annual NO_x concentrations, but can cause high short term concentrations.

Studies are also being planned to determine the optimum process types and control equipment sequence to remove SO_2 and NO_x considering energy, environmental, and economic factors. In parallel with these studies, the NO_x FGT program is directed toward full scale demonstration of the technology by the early to mid-1980's. The first phase in this program will be demonstration of FGT processes at the pilot plant scale. Two pilot plant projects are currently planned: one project will be for removal of 90% of the NO_x in the presence of high or low concentrations of SO_x, and the other project will be for simultaneous removal of 90% of both NO_x and SO_x.

Program Discussion

An alarming increase in NO_x emissions from stationary sources is projected to occur in the next decade. It is uncertain what level of NO_x control will be necessary to prevent an adverse environmental impact of these emissions. Since the NO_x FGT program has the capability for high NO_x removal efficiencies, it is an integral portion of EPA's plan to ensure that technology is available to achieve and maintain the NAAQS for future generations. The major findings to date are:

(1) In the event environmental problems and control strategies require high NO_x removal efficiencies from combustion sources, FGT processes have the capability to meet these requirements.

(2) Selective catalytic reduction processes for removal of more than 90% of the NO_x are commercially available for gas- and oil-fired sources and soon will be commercially available for coal-fired sources in Japan.

(3) Wet processes have the potential for achieving high removal efficiencies of both SO_2 and NO_x more economically than the sequential installation of SO_2 and NO_x FGT control equipment.

(4) The EPA R&D program for NO_x FGT has been formulated to provide assessments of the technology for input into control strategy/technology development and to provide demonstrated technology by the mid-1980's for coal-fired sources.

CONCLUSIONS

The NO_x control technology R&D program continues to show considerable advances in emissions control techniques which should prove applicable to a broad range of combustion sources. These techniques offer the potential both for lower pollutant emissions and improved efficiency and conservation of energy. The greater emphasis on utilization of coal to meet the nation's future energy requirements places much added importance on the requirement for combustion controls to effectively reduce the emissions related to fuel-bound nitrogen. Especially, meaningful demonstrations of sufficient duration are needed to determine in detail the performance of (1) optimum CMs for all major classes of utility boilers, (2) the application of similar CMs to industrial boilers, and (3) improved low NO_x burners for both utility and industrial boilers. At the same time, to support the strategy of maximum stationary source technology, it is essential to continue program emphasis on (1) the development of effective controls for other major stationary point and area combustion sources, and (2) the development and assessment of FGT technology for NO_x control. Therefore, the IERL-RTP NO_x control program is dedicated to the goal of continuing an effective R&D effort:

(1) to advance the technology for NO_x control from stationary sources,

(2) to involve and encourage the participation of key segments of the private sector (e.g., equipment manufacturers, utility and industrial users, research organizations, and universities), and

(3) to promote the transfer and exchange of data and information leading to the effective improvement in design and operation of processes and equipment for improved performance (both from an environmental and energy viewpoint).

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ENVIRONMENTAL MANAGEMENT OF EFFLUENTS AND SOLID WASTES FROM STEAM ELECTRIC GENERATING PLANTS

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INTRODUCTION

Modern fossil-fueled, steam-electric generating plants present the full spectrum of potential environmental problems--air, water, and solid waste. Control of power plant air pollution is being extensively discussed in other papers at this Conference. This paper is primarily concerned with the water and solid waste areas. Essentially all of the solid wastes, excluding bottom ash, are generated as a result of air pollution control devices (e.g., mechanical ash collectors, electrostatic precipitators, baghouses, scrubbers) to control emissions of fly ash and sulfur dioxide. These solid wastes, in turn, present their own potential water pollution problems once they are removed from the control devices for disposal. There are other potential water pollution problems, such as coal pile drainage, boiler cleaning wastes, chlorinated cooling system discharges, and cooling tower blowdown. In addition, the cooling systems present other potential environmental problems such as damage to aquatic life through intake structures, consumption of large quantities of water (lost through evaporation), and cooling tower emissions (plume drift, fogging).

The environmental legislation of the past several years provides the framework for regulation of these effluents and solid wastes. However, characterization of these effluents and wastes, and the development of technology to minimize their adverse environmental impacts have, in a number of cases, required significant research and development efforts. The need for these efforts was the basis for the formulation of the program described herein.

The program for environmental management of effluents and solid wastes from steam-electric generating plants, hereinafter referred to as the "Waste and Water Program," is divided into five areas:

(1) Flue Gas Cleaning (FGC) Waste Disposal
(2) FGC Waste Utilization
(3) Water Recycle/Treatment/Reuse
(4) Cooling Technology
(5) Waste Heat Utilization

Each of these program areas includes a number of projects; these are listed in Table 1. The discussion which follows will address results from the five program areas in the order listed above.

TABLE 1. PROJECTS IN THE WASTE AND WATER PROGRAM

Project Title	Contractor/Agency
FGC WASTE DISPOSAL	
FGC Waste Characterization, Disposal Evaluation, and Transfer of FGC Waste Disposal Technology	The Aerospace Corporation
Lab and Field Evaluation of 1st and 2nd Generation FGC Waste Treatment Processes	U.S. Army Corps of Engineers Waterways Experiment Station
Ash Characterization and Disposal	Tennessee Valley Authority
Studies of Attenuation of FGC Waste Leachate by Soils	U.S. Army Materiel Command Dugway Proving Ground
Establishment of Data Base for FGC Waste Disposal Standards Development	Stearns, Conrad and Schmidt Consulting Engineers, Inc. (SCS Engineers)
Shawnee FGD Waste Disposal Field Evaluation	Tennessee Valley Authority The Aerospace Corporation
Louisville Gas and Electric Evaluation of FGD Waste Disposal Options	Louisville Gas & Electric Company (Subcontractor: Combustion Engineering)

(continued)

TABLE 1 (continued)

FGD Waste Leachate-Liner Compatibility Studies	U.S. Army Corps of Engineers Waterways Experiment Station
Lime/Limestone Wet Scrubbing Waste Characterization	Tennessee Valley Authority
Dewatering Principles and Equipment Design Studies	Auburn University
Conceptual Design/Cost Study of Alternative Methods for Lime/Limestone Scrubbing Waste Disposal	Tennessee Valley Authority
Evaluation of Alternative FGD Waste Disposal Sites	Arthur D. Little, Inc.
FGC WASTE UTILIZATION	
Gypsum By-Product Marketing Studies	Tennessee Valley Authority
Lime/Limestone Scrubbing Waste Conversion Pilot Studies	Pullman-Kellogg
Fertilizer Production Using Lime/Limestone Scrubbing Wastes	Tennessee Valley Authority
Use of FGD Gypsum in Portland Cement Manufacture	Babcock & Wilcox & others
FGD Waste/Fly Ash Beneficiation Studies	TRW, Inc.
WATER RECYCLE/TREATMENT/REUSE	
Assess/Demonstrate Power Plant Reuse/Recycle	Radian Corporation
Characterization of Effluents from Coal-Fired Power Plants (Waste and Water Only)	Tennessee Valley Authority
Treatment of Power Plant Wastes with Membrane Technology	Tennessee Valley Authority
Power Plant Cooling Tower Blowdown Recycle by Vertical Tube Evaporator with Interface Enhancement	University of California-Berkeley
Treatment of Flue Gas Scrubber Waste Streams with Vapor Compression Cycle Evaporation	Resources Conservation Company

(continued)

TABLE 1 (continued)

Project Title	Contractor/Agency
COOLING TECHNOLOGY	
Optimizing Design Specifications for Large Dry Cooling Systems	PFR Engineering Systems, Inc.
Feasibility Study for a Direct, Air-Cooled Condensation System	R.W. Beck and Associates
Dry Cooling Tower Demonstration and Performance Study	Town of Braintree, Massachusetts
Wet/Dry Cooling Tower Study	United Engineers & Constructors, Inc.
Demonstrate Wet/Dry Cooling Tower Technology	Tennessee Valley Authority
Wet/Dry Cooling Tower Test Module Program	Southern California Edison Company
Economic Assessment of Backfitting Power Plants with Closed Cycle Cooling Systems	University of Iowa
Mechanisms to Reduce Intake Structure Effects at Power Plants	Tennessee Valley Authority
Alternatives to Chlorination for Control of Condenser Tube Biofouling	Monsanto Research Corporation
Bromine Chloride - An Alternative to Chlorine for Fouling Control in Condenser Cooling Systems	Martin Marietta Corporation
WASTE HEAT UTILIZATION	
Beneficial Uses of Warm Water from Condensers of Electric Generating Plants	Northern States Power Company
Soil Heating to Extend Crop Growing Season	Tennessee Valley Authority
Optimization of Biological Recycling of Nutrients in Livestock Wastes for Utilizing Waste Heat	Tennessee Valley Authority
Horticulture Economic Quality Control Study	Vermont Yankee Nuclear Power Corporation
Potential Beneficial Use of Industrial Waste Heat for Greenhouse Production of Bedding Plants, Cut Flowers, and Foliage Plants	Fort Valley State College

TECHNICAL DISCUSSION

FGC Waste Disposal

Coal-burning power plants in the U.S. produce large quantities of wastes that accumulate in ash-collection devices or flue gas desulfurization (FGD) systems. Since coal use is being encouraged and since FGD systems are often necessary to reduce sulfur oxide emissions, the rate of ash and FGD sludge production is expected to grow rapidly. Most of the U.S. utility installations of nonregenerable (e.g., lime/limestone) scrubbing systems have used disposal methods similar to those for ash disposal; i.e., ponding and landfill. Two major environmental considerations are inherent in disposal of FGD sludge: (1) the water pollution potential of soluble materials, and (2) the land degradation potential of physically unstable wastes.

FGD sludge chemical characteristics, to a large degree, have been quantified. Sludge liquors exceed drinking water standards for total dissolved solids (TDS), with high concentrations of calcium, sulfate, and chloride (and in some cases, magnesium and sodium). In addition, excessive concentrations of several trace metals have been noted. The chemical composition of FGD sludge solids consists of calcium sulfite hemihydrate, calcium sulfate dihydrate (gypsum) and/or hemihydrate, and calcium carbonate, plus any fly ash collected in the scrubber. The percentage of each solid constituent is primarily a function of the alkaline additive (e.g., lime, limestone), the percent sulfur in the coal, and the manner in which the scrubber system is operated (e.g., whether forced oxidation is applied, whether fly ash is collected separately). Although the fly ash has been shown to be a major contributor of trace elements to the sludge solids and liquor, separate collection of fly ash does not necessarily mean that concentrations of all these elements in the sludge liquor will be insignificant.[1]

The physical properties of FGD sludge vary considerably from system to system; chemical composition is related to, but does not adequately define, the size and type of the sludge solid crystals. For example, in comparing the lime and limestone scrubber solids from the EPA/TVA Shawnee test facility, the limestone scrubber solids were found to be primarily individual platelets or "rosette" aggregates, while the lime scrubber solids were primarily spherical aggregates with somewhat better settling and dewatering properties.

The relationship between scrubber operating parameters and the characteristics of the calcium sulfite crystals has not yet been adequately defined. Hopefully, a procedure will be developed to obtain consistent, easily dewatered sulfite solids. An alternative approach would be to use forced oxidation to produce only gypsum crystals, which are normally much larger than calcium sulfite crystals. A complementary approach is to improve the performance of dewatering equipment. Separation of the clarification and thickening steps can result in improved performance of gravity settlers, with a substantial reduction in the equipment size.

Many FGD sludges tend to liquefy easily, even after substantial dewatering. Several approaches to improving physical stability continue to be studied, including stabilization using underdrainage and compaction, production of gypsum, and chemical treatment ("fixation") for landfill. Chemical treatment of FGD sludge has been shown to result in significant structural improvement, a 50-75 percent reduction in major solubles (e.g., chloride) in the leachate and an order of magnitude (or more) reduction in permeability. Further testing of these disposal methods, including revegetation (reclamation) of disposal sites, is planned.

The costs of FGD sludge disposal vary considerably, depending on the disposal system design, and site-specific factors such as labor costs or the cost of a pond liner (if one is installed). Preliminary cost estimates for a typical high-sulfur coal-burning plant are about $4-$9 per metric ton (dry basis, including ash) for ponding, and about $8-$12.50 per metric ton (same basis) for chemical treatment and landfill.[2] The ponding costs do not include reclamation costs. More detailed economics for these disposal methods are being defined.

Coal-mine disposal of FGD sludge has greatly interested engineers in the flue gas desulfurization industry for many years, because of established means of transportation between the coal mine and the power plant, and the need for material to fill the void left by mining of the coal. In addition, many plants may not have sufficient land area for on-site disposal. Recent technical/economic assessments indicate that active Midwestern surface mines and Eastern/Midwestern room-and-pillar underground mines are the most promising candidates for this disposal approach.[3] Field tests of this approach are required to bring it to commercialization.

Ocean disposal of FGD sludge is also being assessed because many plants in the Northeast may have difficulty switching to coal for lack of disposal sites; however, many of these plants do have access to the ocean. It was also recognized that the major soluble chemical constituents in FGD sludge are found in relatively high concentrations in seawater. Further environmental/economic studies of this option are needed to establish its viability.

Currently there are no Federal regulations which specifically address the disposal of FGD sludge. However, the Resource Conservation and Recovery Act (RCRA) of 1976 calls for the eventual Federal regulation of disposal of hazardous solid wastes and the issuance of guidelines (to be used by the states) for disposal of non-hazardous solid wastes. The RCRA specifically identifies solid wastes and sludges, including those generated by air pollution control devices, as being covered by the Act. Although no official designation (hazardous or non-hazardous) has been placed on FGD sludges, it is currently assumed that they will be considered non-hazardous, with disposal guidelines to be issued in the next 2-3 years. Technical support for this effort is underway.

Studies of the characteristics of coal ash and the effects of coal ash disposal have been underway and are continuing. Although these efforts are not as extensive as those for FGD sludge, they are no less significant because of the increasing generation of coal ash. A report has been issued which summarizes and evaluates existing data on the characteristics of coal ash from studies made by TVA and others.[4]

FGC Waste Utilization

Although extensive utilization of coal ash and FGD sludge is practiced elsewhere[3], less than 20 percent of the coal ash produced in the United States is currently used[5], and there have been no full-scale commitments by American utilities to produce FGD gypsum for sale. This situation may change as the utilization of coal for electric power expands and an energy and resource conservation ethic begins to take shape. The utilization of coal ash is being promoted by many commercial organizations, spearheaded by the National Ash Association, which was formed in the late 1960's. The utilization of FGD sludge is expected to progress more slowly because of the need to demonstrate commercial viability, but this need should be filled in the near future.

A preliminary study conducted by TVA in early 1974 indicated the possibility that production of FGD gypsum might offer a substantial economic advantage over FGD sludge disposal. The production of FGD gypsum is practiced extensively in Japan; in 1975, over 1 million metric tons of gypsum was produced, primarily for use in wallboard and portland cement.[6] However, prior to the use of FGD in Japan, gypsum was imported at considerable expense; therefore, there was a substantial market opportunity. The lack of disposal sites for FGD sludge was another major incentive.

To determine the marketability of FGD gypsum in the United States, a thorough economic evaluation of gypsum-producing FGD systems and detailed marketing studies were undertaken. Indications are that processes less complex than the majority of those used in Japan will be necessary for a profitable situation to occur.

The use of FGD sludge as a filler material and source of sulfur for fertilizer is another potential utilization scheme. Further development of the fertilizer production process is needed to establish its viability, as are plant toxicity studies.

Conversion of FGD sludge to elemental sulfur with recovery of calcium carbonate for recycle to the scrubber has been studied on a pilot level by Pullman-Kellogg and Ontario Hydro.

Water Recycle/Treatment/Reuse

Minimization of water consumption and discharges in the electric utility industry are the current regulatory trend. The ultimate goal is "zero discharge". Complete recycle and reuse with side-stream treatment is the only way to achieve zero discharge. However, in some cases, particularly those involving existing plants, total elimination of discharges is not feasible, so treatment prior to discharge is required for some plant streams. Nevertheless, in almost all cases, significant improvements in water utilization can be made, often without major expense.

The major limitation in the recycle and reuse of major plant streams (e.g., cooling tower blowdown, ash sluice water) is the buildup of dissolved salts. Chemical treatment to precipitate compounds (e.g., calcium sulfate) can increase the number of cycles in the major systems, but eventually the more soluble salts build up and have to be purged. Treatment of the purge streams requires more expensive techniques such as evaporative or membrane processes. Improvement of the performance of these techniques is needed to lower the costs of "zero discharge." Although more energy-intensive, the evaporative processes seem to be the most widely applicable.

Waste streams which may require treatment prior to discharge include boiler cleaning wastes and coal pile drainage. Metals in these wastes are of particular concern. Membrane processes appear to be promising for treatment of alkaline boiler cleaning wastes. Routing coal pile drainage into alkaline ash ponds appears feasible for control of metals in the acidic drainage. At plants where ash is collected dry, treatment of the drainage (e.g., with lime), would be necessary. Treatment methods for toxic effluents not currently covered by the effluent guidelines have not yet been specified by EPA.

Cooling Technology

The technological basis for no thermal discharges to natural receiving waters is the closed cycle evaporative system; e.g., wet cooling tower, cooling pond or lake, and spray cooling system. In water-scarce areas or locations where water acquisition and treatment costs are high, a dry cooling system may be advantageous for a power plant. A hybrid cooling system, consisting of both wet and dry components, may offer economic advantages over a dry system while meeting water supply constraints. However, experience with both dry and wet/dry cooling systems for power plants in the U.S. is lacking. Although dry cooling systems for plants rated at 200 MWe or less are operative abroad, two 20 MWe units (at Wyodak, Wyoming, and Braintree, Massachusetts) represent dry cooling system applications in the U.S. A 330 MWe unit at Wyodak, which is scheduled for commercial operation in 1978, will also use dry cooling. The first wet/dry cooling system (for a 500 MWe unit at Fruitland, New Mexico) is expected to save 60 percent of the water that would be needed by an all-wet cooling tower when it becomes operational in 1979.

When compared to the once-through cooling system, all evaporative systems consume more water and are generally less efficient because of higher turbine exhaust pressures. These factors lead to higher total annual costs for evaporative systems. The large evaporation rates of water, since about 80 percent of the total cooling is effected by evaporation, can also lead to potential fogging, deposition of liquid droplets at undesired locations, and disposal problems for concentrated cooling tower blowdown.

A dry cooling tower may cost up to an order of magnitude more and operates with larger energy and capacity penalties than a wet tower. The greater cost and reduced performance are related to a significant difference in operating principle. The performance and size of a dry tower depend on the ambient dry bulb temperature, which is never less than and infrequently equals the wet bulb temperature, and involves only sensible heat transfer; the wet bulb temperature and evaporative heat transfer characterize wet tower operation. A dry tower is thus larger than a wet tower, for a given heating load, but consumes no cooling water except for the make-up required to replace small losses, such as those through pump seals.

Important considerations in power plant siting and closed cycle cooling system selection are consumptive water use, vapor plume emissions, and cost. Optimizations based on lowest total annual cost are often the criteria for selecting cooling systems. Using these evaluation factors, dry cooling systems minimize water consumption and permit minimum siting constraints but are usually several times more expensive than wet cooling systems. Wet/dry cooling systems are intermediate to separate wet and dry cooling systems in both cost and water consumption and are suitable for operation in many water-limited regions. They can also offer significantly lower cost than dry systems while providing effective means to minimize fogging and drift.

Adverse environmental impacts, such as damage or destruction of benthic, planktonic, and nektonic organisms, may be related to intakes of cooling systems. Current guidelines for intake structures recognize the best technology to be dependent on site-specific factors which require case by case decisions[7]. Thus, the intake volume of water, number and types of organisms entrained or entrapped, intake geometry, thermal characteristics, chemicals added to water for biological control and other factors are pertinent to assessing environmental impacts of an intake and the related flow system. Although numerous intake concepts have been tested, most have had limited applicability to power plant intakes and were designed primarily to reduce fish losses.

Most power plants in the U.S. use chlorine for the control of biological fouling in their cooling systems, especially in the condenser tubes for both open and closed cycle cooling. The use of chlorine is believed to have toxic effects on aquatic organisms in receiving waters[7], and free chlorine is said to react with some organic compounds to form carcinogens, which are of great concern if they enter public drinking water sources.[8] EPA has established allowable concentrations of free chlorine in new plant effluents, and some states have established their own limits on chlorine discharge while others have none. Alternatives to current chlorination practices, such as use of other chemicals, physical/chemical treatment, and mechanical cleaning, exist but are less economical.[8]

Waste Heat Utilization

The beneficial use of rejected heat from a power plant cooling system can (1) reduce air and water pollution, (2) conserve energy through fuel conservation, (3) reduce the cost of pollution control equipment, (4) provide additional revenue from the sale of this form of energy, and (5) eliminate the adverse environmental and economic impacts associated with the fuel required if waste, or rejected, heat was not used beneficially.

Since the discharge temperature of power plant condenser cooling water is low (about 5 to 20°C above intake water temperature), the corresponding heat is of low quality, and its application has usually been for agricultural (greenhouse) and aquacultural purposes. Greenhouse applications, involving high value crops such as selected flowers and vegetables, appear to be the most economical uses of waste heat. Aquacultural applications, unless the waste heat is supplied to other than natural receiving waters, do not reduce thermal pollution as do agricultural uses: the waste heat primarily regulates water temperature to promote more rapid growth of the fish or shellfish of interest.

PROGRAM DISCUSSION

FGC Waste Disposal

This portion of the Waste and Water Program is designed to evaluate, develop, demonstrate, and recommend environmentally acceptable, cost-effective techniques for disposal of FGC wastes, with emphasis on flue gas desulfurization (FGD) sludge. This program area includes twelve projects, four of which are being conducted by TVA under an Interagency Agreement with EPA (see Table 1). Contracted efforts in this area were initiated in late 1972.

Results in this program area have been substantial. Chemical characterization of FGD sludge has shown the need for protection of drinking water supplies from intrusion by sludge leachates; physical characterization has shown the need for stabilization to reclaim the disposal site. Chemical treatment appears to offer the best overall approach for fulfilling these needs, but a variety of approaches will probably be applied, depending on the nature of the sludge and the disposal site. Costs of disposal are a major factor in determining the approach, and they represent a major part (up to 20 percent) of the capital and operating costs of an FGD system. These costs can be drastically reduced by improved absorbent (e.g., limestone) utilization, controlled solids quality, and by improved sludge dewatering equipment. All of these improvements have been shown to be feasible and are currently making their way into the process supply market. However, further development/refinement of these techniques is continuing; their full commercial use is expected in the next 2-3 years.

Because of the substantial land requirements for on-site disposal of ash and FGD sludge, there is much electric utility interest in off-site disposal, particularly disposal in coal mines. Assessments of this alternative have shown area surface mines to be most attractive. One utility plans to begin disposal of FGD sludge and ash in a surface mine this summer. Plans under the Waste and Water Program are to conduct a 2-year monitoring/assessment effort at this utility site. Successful demonstration of this disposal approach could make conversion to coal quite feasible even in areas where land for disposal is limited.

Field tests of various FGD sludge disposal options, including ponding of untreated sludge, physical stabilization using underdrainage, and landfill of chemically treated sludge, continue. Revegetation of FGD sludge disposal sites is also under study. Detailed economics of several disposal options are being defined; the initial phase of this effort, which includes ponding and chemical treatment/landfill, has recently been completed. The next phase will probably include onsite gypsum disposal and disposal of FGD sludge in coal mines.

Guidelines for disposal of FGD sludge and coal ash are expected to be issued within the next 2-3 years. An effort has been underway since mid-1975 to prepare a preliminary technical support document which could be potentially useful in setting FGD waste disposal guidelines. A draft of the document is currently under review and is expected to be issued in mid-1977.

Studies of ocean disposal of FGD sludge have identified several potential environmental problems. It appears that these problems could be alleviated by either chemical treatment to a "brick-like" form (possibly creating an artificial reef) or oxidation to gypsum (followed by a widely dispersed disposal operation). The costs of these approaches are being defined and are expected to be somewhat higher than for chemical treatment/landfill near the plant. Pilot disposal simulation studies are underway to define the environmental effects of both untreated and treated FGD sludge disposal in the ocean.

FGC Waste Utilization

This portion of the Waste and Water Program is designed to evaluate, develop, and demonstrate cost-effective techniques for utilization of FGC wastes, with emphasis on FGD sludge. This program area consists of five projects, two of which are being conducted by TVA (see Table 1).

Since FGD sludge is a relatively new byproduct, utilization in the United States is not yet a commercial reality. However, conversion of FGD sludge to gypsum (or direct production of gypsum) for use in wallboard and portland cement manufacture is practiced extensively in Japan. Although the Japanese experience has primarily been with oil, gypsum-producing FGD experience with coal is increasing in Japan and the United States. Studies under this program and the FGD program show FGD gypsum production to offer major operational, economic, and in some cases environmental advantages.

Tools for the development of market strategies have been developed. Studies currently underway include a thorough economic evaluation of several gypsum-producing FGD processes--i.e., limestone/gypsum, Chiyoda (H_2SO_4/gypsum), and Dowa (aluminum-based double alkali/gypsum)--and a detailed U.S marketing study of FGD gypsum for wallboard. A report on this study is expected in mid-1977. Wallboard production using FGD gypsum from a Southeastern utility has been successfully demonstrated. Feasibility demonstration of FGD gypsum use in portland cement manufacture in cooperation with trade associations is planned.

Development of FGD sludge utilization in fertilizer is continuing at the pilot level. Spreading the material over a relatively large land area in this manner would not only alleviate the disposal problem, but would also minimize the potential localized environmental impact of a highly concentrated waste; i.e., the leachate's chemical constituents would be highly diluted by rainfall and interaction with the soil.

Current plans call for pilot scale development of a sulfur-producing limestone scrubbing system which uses coal as the reductant. The process also regenerates the calcium carbonate for recycle to the scrubber. This effort should be underway by mid-1977.

The use of coal ash, particularly in the construction industry, is practiced worldwide; however, a considerably greater amount could be used in the United States than is currently consumed. Coal ash is also a potential source of metals, particularly iron and aluminum. However, studies under this program show that coal ash still does not appear to be competitive with bauxite as a source of aluminum, even though the price of alumina has more than doubled in the last few years.

Water Recycle/Treatment/Reuse

This portion of the Waste and Water Program is designed to evaluate, develop, and demonstrate cost-effective techniques for minimizing water consumption and discharges through recycle/reuse as well as techniques for treatment of in-plant streams for reuse or discharge within effluent guidelines. This program area consists of five projects, two of which are being conducted by TVA (see Table 1). Demonstration of the technology to achieve zero discharge would be a significant step toward meeting current and future effluent guidelines. The waste and water program has undertaken a variety of activities toward that goal. The design tools to provide for broad-scale application of the technology necessary for minimization or elimination of effluents will ultimately be provided by this program.

Five power plants have been studied to examine the alternatives for minimizing water use (and discharges) in the major plant systems; e.g., cooling towers, ash sluice systems, and wet scrubbers. Results have shown that much more efficient water use can be obtained, in many cases without significant expense. Evaluation of system designs are being completed; planning for large-scale demonstration of water recycle/treatment/re-use at a utility is in the final stage

Several water treatment systems are being examined to address the problem of dissolved salts in recycle streams, including vapor-compression cycle evaporation, vertical tube evaporation with interface enhancement (for better heat transfer), and reverse osmosis (RO). Results, so far, show evaporation systems to be more generally applicable to major streams.

Treatment of other streams to meet effluent guidelines is also underway. Hollow-fiber reverse-osmosis membranes appear promising in the treatment of alkaline boiler cleaning wastes, a minor (in terms of volume), but not insignificant, waste stream. Ultrafiltration membrane processess are being tested for oil removal from waste streams. In addition, coal pile drainage is being characterized at two plants to correlate drainage with rainfall and determine treatment requirements. Sampling frequency requirements are being defined for ash pond overlow at two plants; so far, quarterly sampling appears adequate for most chemical parameters. Finally, an assessment of technology for control of toxic effluents, including technology from other industries, is currently underway.

Cooling Technology

Cooling technology projects concern studies of cooling system economics and advanced heat rejection techniques, development of control technology for the treatment and reuse of cooling effluent streams, and demonstration of new cooling technology. A brief summary of projects under this aspect of thermal pollution control follows.

Several studies of dry cooling systems have been or are being supported by EPA. One study involved optimizing the design of large dry cooling systems.[9] Computer program variables included: heat exchanger design parameters (tube length, bundle width, number of tubes and passes), turbine type (conventional or modified back pressure), type of condenser (jet or surface), climatic factors (ambient dry bulb temperature and its duration), temperature differences (initial temperature difference in the dry tower, cooling water range, terminal temperature difference in the condenser), and cost factors (auxiliary fan power, cooling system capital, penalty and operating costs, fixed charge rate). The analysis showed that there are many combinations of design variables which result in the same total annual cooling system cost. Consequently, the cost, being a function of six variables, cannot be simply illustrated on a two-dimensional plot as has often been done, and no single point representing the absolute minimum cost exists because of compensating effects among the variables. Thus, no single variable dominates the cost, and fixing some design variables at constant values can produce non-optimum results. Plant site, turbine and condenser types, and tube configuration and length can also significantly affect total annual cost.

Another dry cooling study with EPA support is a demonstration of a 20 MWe system which is part of an 85 MWe combined cycle plant. After a favorable feasibility study for the project[10], a 4-year test program was developed. Specific objectives of this dry cooling system demonstration are to monitor and evaluate: (1) steam flow and temperature in the dry tower to better define optimum design characteristics, (2) the meteorological effects from the plant and the meteorological impacts on plant operation and performance, (3) noise generation and its control, (4) air quality factors related to plant operation, and (5) economic effects of the design and operational factors. Data collection is expected to begin in July 1977, and a final report on the project is slated for early 1980.

A project for evaluting the technical and economic feasibility of wet/dry cooling towers for water conservation and vapor plume abatement has been completed, and the final report is being prepared. Cost optimization studies for 1000 MWe fossil-fueled power plants at 10 sites were made. Six sites (five mine-mouth sites in the semi-arid but coal-rich Western U.S. and one in New York State which will require coal shipments) were evaluated for water conservation while four urban sites (Charlotte, Cleveland, Newark and Seattle) were used in the plume abatement analyses. Site-specific information included elevation, make-up, water quality, ambient wet and dry bulb temperature, and other pertinent meteorological data. Using the total evaluated cost of the cooling system (defined as the sum of capital and penalty costs) and optimized separate state-of-the-art wet and dry towers as reference systems, costs as a function of water consumption, or the make-up required, for the wet/dry system were related to the percentage of water required by the separate all-wet system. For the sites studied the wet/dry system met water consumption constraints at costs slightly above the all-wet system and significantly below those for the all-dry system. Wet/dry systems which save as much as 98% of the make-up required by an all-wet tower can still have an economic advantage over an all-dry system, but where water is available the all-wet cooling tower will be the economic choice in most cases.

Low profile wet cooling towers can significantly reduce ground fogging by employing more cells to reduce the liquid concentration in the plume. This change can be made without a significant increase in total evaluated cost for the wet cooling tower. Wet/dry towers were used to meet restrictive site conditions or fogging limitations at a cost of 2 to 3 percent more than for all-wet systems at the sites studied.

A joint EPA/TVA project also involves wet/dry cooling. This program recently resumed after a decision by the Government Accounting Office approved the acquisition of the tower which is located on non-government-owned land. This study concerns a wet/dry system that can operate in a series or parallel air flow arrangement. Thermal performance, wet/dry plume characteristics, and noise characteristics will be evaluated in this Interagency Energy project. The test data will be used to verify and revise the cooling tower design, the tower performance computer model, the computer model for predicting visible vapor plume behavior, and the computer model for estimating noise levels associated with both the wet and dry tower operation.

Since experimental data on wet/dry cooling are lacking, EPA has joined with nine other sponsors to field test a wet/dry cooling tower at a power plant in California. Using a tower designed and now being erected by a cooling tower manufacturer, the testing will provide data on water conservation and plume characteristics as well as a test of the tower design and operation.

The effluent guidelines for the steam electric generating industry[11], which were published in October 1974 and remanded by an appeals court in July 1976, required closed cycle cooling systems for power plants according to their age and size. An economic assessment of backfitting closed cycle cooling systems[12] to affected plants (completed in March 1976) considered both mechanical and natural draft wet cooling towers, cooling ponds, and spray canals. Results of the study revealed that the total cost of backfitting depended mainly on the capital cost of the cooling system; but the capital cost of replacing lost capacity, operating cost of peaking plants, and added fuel costs stemming from the use of closed cycle in lieu of once-through cooling were also significant costs. The mechanical draft tower was the least expensive backfitted cooling system for the sites considered; however, great care in assessing the costs cited and the fixed charge rate for each application was suggested by a sensitivity analysis of the total cost.

An extensive review of intake structures[13] was made in another EPA/TVA project under an Interagency Energy Agreement. This state-of-the-art evaluation of mechanisms and intake designs concerned intake configurations, behavioral barriers to fish, screening devices, and fish removal systems. Evaluations of available intake technologies were summarized, results of recent tests and studies were presented, and recommendations for tests needed to demonstrate a fish protection mechanism at a given site were made. In a related effort under the Agreement, TVA is designing a dual flow, vertically traveling intake screen with the objective of reducing fish impingement and entrapment.

Alternatives to chlorination for control of biological fouling in condenser tubes were assessed in a recent report.[8] The results of this study indicated that: (1) mechanical cleaning systems are relatively expensive, difficult to retrofit in some instances and may also be inadequate without some chlorination; (2) ozonation is unproven for power plant water treatment and is high in both capital and operating costs; (3) dechlorination with sulfur dioxide requires an additional chemical feed system and possible deoxygenation of receiving waters; (4) bromine chloride may be a viable alternative to chlorine but further study of its use is needed; (5) currently available techniques permit attaining newly established free chlorine limits in new plant effluents; and (6) several methods for biofouling control which use chlorine are more efficient and cause fewer problems than continuous chlorination. In a follow-up study, bromine chloride is being evaluated as it appears to have fewer adverse environmental effects although it is more costly than chlorine.

Waste Heat Utilization

Current waste heat utilization projects being supported by IERL-RTP are mainly concerned with greenhouse applications, although promising residential/industrial (such as cogeneration) and aquacultural uses of waste heat are also of interest. The greenhouse applications have focused on flower, vegetable, and tree seedling production when heating was supplied by soil and air warming or air warming alone.

In a greenhouse demonstration, partially funded by EPA, warm water from the condenser cooling loop provides both soil and air heating for a 0.2 hectare greenhouse.[14] The warm water system, using water generally at 29.5°C, supplied all the greenhouse heating while maintaining suitable greenhouse temperatures for the production of roses, snapdragons, tree seedlings, tomatoes, and lettuce during Minnesota's coldest winter in 100 years. Warm water heating costs were estimated to save $25,362/hectare year over fuel oil in the Minneapolis area. With the technical and economic feasibility of using power plant waste heat for greenhouse heating having been demonstrated, commercialized greenhouses with warm water heating at this site appear likely within the next few years. Serious discussions between interested commercial growers and Northern States Power Company have indicated that present plant capabilities can support about 5.7 hectares of greenhouses and stimulated some consideration to supporting 40.5 hectares of greenhouses after the initial development.

A cooperative effort between EPA and TVA has involved both agricultural and aquacultural uses of waste heat. The agricultural application concerned soil warming studies in a program aimed at extending the crop growing season. Preliminary results have permitted selection of warm water piping material and spacing arrangement. Crop growth data will be obtained in follow-up studies. The aquacultural application studied the feasibility of using waste heat for optimizing the recycling of nutrients from swine manure for the production of algae. The algae were then fed to amur fish which were in turn used for livestock feed supplements. This study is continuing.

Warm water at 18-22°C from the cooling system of a New England nuclear plant will also be used for greenhouse heating. Scheduled for completion in late 1977, this application will determine the feasibility of using relatively low temperature warm water for commercial horticulture.

Another project, a 2-year one to be completed in 1978, uses warm water for both soil and air heating at a Southeastern site. This greenhouse use of waste heat will be evaluated as a means of enhancing the growth of bedding and foliage plants and selected flowers.

CONCLUSIONS

The Waste and Water Program is designed to characterize effluents and solid wastes from power plants and to develop technology to minimize the potential adverse environmental impacts of these effluents and wastes. The program has achieved significant results in a number of areas.

Flue gas cleaning (FGC) wastes have been characterized physically and chemically; a variety of disposal options have been identified. Disposal of these wastes in coal mines is economically attractive and, therefore, is being investigated through lab and field tests. Methods for achieving major cost reductions in FGC waste disposal have also been identified and are making their way into the process supply market. These include oxidation to gypsum and improved dewatering equipment.

Production of saleable FGD gypsum is technically and economically feasible, given a proper match of power plant and manufacturing plant (e.g., for wallboard, cement). Domestic markets currently need better definition. The use of coal ash is current commercial practice although much greater utilization is feasible.

Overall power plant water recycle/reuse studies have shown that much more efficient water use can be obtained, in many cases without significant expense. Treatment systems to maximize water reuse are being evaluated in EPA and privately funded studies and the improved evaporative systems appear promising. Studies of effluent treatment prior to discharge are also underway.

The cooling system studies have shown that:

1. various combinations of dry cooling system variables can produce the same total annual cooling system cost and no single combination of design variables represents the absolute minimum because of compensating effects among the variables,

2. wet/dry cooling towers can operate with water savings up to 98% of the make-up required by an all-wet tower and still have an economic edge over an all-dry system,

3. wet/dry cooling towers may be operated to effectively limit ground fogging and to reduce plume emissions, and

4. alternatives to chlorination for biofouling control in power plant cooling systems while effective are generally more costly.

Waste heat is effective for greenhouse soil and air heating. The technical and economic feasibility of using warm condenser cooling water from a power plant for soil and air heating in a Minnesota greenhouse to produce high-value vegetables and flowers has been demonstrated. Commercial greenhouses heated by power plant waste heat at this site are likely within the next year or so.

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CHAPTER 4

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EXTRACTION AND BENEFICIATION

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MAJOR RELIANCE ON COAL

Without question, major reliance will be placed on coal as the short- to intermediate-term answer to much of this nation's energy problem. Coal will be used directly as fuel for conventional steam generation and will eventually be used as the energy source for higher-efficiency energy conversion processes such as MHD. Coal will also become the essential raw material for the emerging synthetic fuel industry. Inevitably, therefore, coal will be mined, cleaned, and transported in ever-increasing amounts. This step in solving the energy crisis has already begun.

How can this use of coal be accomplished in acceptable environmental fashion? Today's papers, which I will summarize, provide an overview of the current interagency research and development efforts to meet this need.

Work on fuel extraction under the immediate direction of EPA has been described by John Martin and Eugene Harris in their paper, "Research and Development Programs for Pollution Control in Mining and Transport of Solid Fuels." Objectives are to (1) assess the potential environmental damages from active and abandoned mining, transporting, and beneficiation processes; (2) develop methods to control, treat, and abate environmental pollutants from these operations; (3) demonstrate the technical/operational feasibility and cost effectiveness of environmental control options; (4) provide environmental control criteria; and (5) prepare user manuals for all pollution control aspects of the mining industry.

EASTERN SURFACE MINING

With regard to problems of eastern surface coal mines, newly developed mining techniques—block cutting, haulback of spoils, mountaintop removal, hollow fills, etc.—have appeared within the last few years. These techniques greatly reduce the hazards of massive landslides, erosion, and stream siltation by containing spoils in specifically engineered sites. Recently initiated projects involve development of proper premining planning practices, assessment of the environmental impact of newly emerging extraction technologies, and demonstration of controls for minimizing off-site damage. A minor effort is continuing in reclamation research to keep abreast of current practice. Example projects in these areas include preparation of a manual for premining planning; projects to evaluate control of pollution through use of block-cut mining, mountaintop removal, and head-of-hollow fill mining techniques; and a project on control of sediment from haul roads.

EASTERN UNDERGROUND MINING

As for eastern underground mines, mine drainage treatment and mine sealing have long been the accepted methods of abatement of pollution. Each, however, has its disadvantages. The treatment process is acceptable for active operations but is expensive and at best a short-term cure. After a mine is closed, treatment must continue for years. Mine sealing is not a miracle cure for mine drainage in that it is successful only in special cases with ideal conditions. Air sealing to prevent oxidation of acid-forming materials has proved to be nearly impossible.

The Deer Park Daylighting Project, currently in the demonstration phase, is an attempt to surface-mine and then reclaim a previously mined area in northwestern Maryland. The project is intended to show that it is feasible, from both energy and environmental standpoints, to strip out an abandoned underground mine, recover the unmined coal pillars, and restore the area to a state of productivity.

Another approach is aquifer dewatering. This project is to show that mine drainage can be reduced by artificially removing or intercepting the ground water in the vicinity of the mine, thus reducing infiltration to the mine void. Other projects are proceeding to investigate the effectiveness of backfilling mine voids with waste materials, to reduce water infiltration to the mine workings, and to develop more effective mine sealing techniques.

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In the mine drainage treatment area, recent work has shown that combinations of neutralizing agents are usually more effective than the same agents used separately. As an example, recent studies involving the use of limestone/lime neutralization techniques have found them to be efficient, less expensive from an operating standpoint, and capable of producing denser floc material for the settling stage than is possible by using lime alone.

Efforts are presently aimed at redefining the applicability of current treatment technology to mining situations other than the eastern coal fields. In addition, work is continuing to develop and demonstrate more advanced treatment techniques, such as ion exchange, reverse osmosis, and neutralosis. To illustrate the current research trends, one active project has as its objective the development of a refined and more efficient system for reverse osmosis treatment of acid drainage using lime neutralization of the resultant brines. Coupled with the treatment projects are efforts for safe disposal of the sludges and brines that are the by-products of neutralization. Studies involving sludge dewatering, lagooning, and spray irrigation are underway.

WESTERN MINING

Mining of western coals presents a slate of new problems. In addition to grading, surface water control, erosion protection, and revegetation work—as required for eastern surface coal mines—western mining must make provision for severe drought conditions, wind erosion, and high-intensity rain storms. Many of the active western mines are open-pit operations that have the potential for major aquifer disruption and extremely difficult reclamation. At present, a large portion of the research deals with definition and assessment of potential environmental impacts. To this end, for example, one project is defining the impacts that mine development would have on ground water, surface water, land use, and socioeconomic structures. Work on revegetation, surface water quality, ground water quality and quantity, and irrigation potentials is also progressing at active mine sites. Simultaneously on this project, the Bureau of Mines and ERDA are collecting data regarding reclamation practices and water-harvesting techniques.

As complementary work, studies of the ground water formations in the coal-producing areas of the West and development of seed sources and planting techniques are being conducted by the U.S. Geological Survey and USDA.

URANIUM MINING

Uranium mining is also encompassed within this general area. The mining of uranium entails a variety of environmental hazards, including surface and ground water contamination, fugitive dust emissions, and solid waste disposal problems created by onsite beneficiation processes. The existing state-of-the-art for mining control technology needs to be assessed, as does the possibility of transfer of technology from similar extractive industries.

In addition to being extracted by conventional mining techniques, uranium is also mined by *in situ* leaching. The environmental impact of solvents utilized in the leaching process is not well known. Currently under consideration are three projects to evaluate the *in situ* extractive process.

SOLID-FUEL TRANSPORTATION

Transportation of solid fuels from mines to points of use can also involve environmental disruption. Work is underway, therefore, to produce a multimedia assessment of such environmental problems and to specify technology needed to minimize the pollutional aspects of solid fuel transport. A user manual comparing various control techniques will be made available. In this the economics and effectiveness of the various control options for each mode of transport will be discussed to provide a basis for selecting or evaluating transport systems. It will deal with the five basic modes of transport—truck, rail, barge, pipeline, and conveyor.

PUBLISHED REPORTS

During the past year, a number of reports have been published on completed efforts. In many cases, the results will be referenced and incorporated in future manuals that will summarize all work undertaken in a given subject area (e.g., eastern surface coal mines). Reports have received wide distribution throughout industry and government and are already being used to design control systems or provide information regarding specific problem areas or designs. The manual entitled "Erosion and Sediment Control" has had wide distribution (over 15,000 copies) and is being used by many engineers, mining companies, and State and Federal agencies for design and evaluation of sediment control structures.

Other completed reports cover use of porous limestone barriers to neutralize acid streams, use of overburden sampling as an aid to premine planning, demonstration of reclamation methods to reduce infiltration to underground workings, effectiveness of various types of sedimentation ponds, treatment of AMD by the alumina-lime-soda process, a model to predict pollution loads and select most cost-effective abatement methods, and a preliminary assessment of the environmental impact of uranium mining and milling.

Feasibility studies or interim reports were published for projects involving underground mine daylighting, debris basin effectiveness for sediment control, surface and underground mine sealing, coal mine haul road sediment control, and use of fly ash for surface mine reclamation. In addition to these, two draft reports are now being reviewed for the major efforts dealing with assessment of coal transport, head-of-hollow fill, and mountaintop removal mining.

Work by the Agricultural Research Service of USDA is described in the paper by J.F. Power and O.L. Bennett. They point out that practically all land disturbed by mining is eventually returned to some type of vegetative cover. Since vegetative cover affects soil/water relations and erosion, soil and water resources on mined land can be protected by controlling the type and amount of vegetation present. Land reclaimed for crop production or grazing can also produce economic benefit. Considerable effort has been expended to identify the physical and chemical properties of mine spoils that could restrict plant growth. This requires appropriate methodology for sampling and analysis. Fortunately, most procedures normally used for agronomic work apply also to mine spoils, and procedures suitable for western United States are being published in a USDA handbook.

FACTORS RESTRICTING PLANT GROWTH

Factors most restrictive to plant growth are often different in eastern than in western mine spoils. In the East, problems result predominantly from the actual or potential acidity of spoils. Also, the amount of magnesium, calcium, and phosphorus is sometimes insufficient to support growth, and many eastern spoils contain a high sand percentage, which tend to make them droughty. Furthermore, much of the eastern mining results in steep outer slopes which are erosive and difficult to stabilize. In western United States, however, the primary problems in revegetation of mine spoils are related to efficient conservation and use of the limited quantity of precipitation received. These include such factors as high salinity levels, high exchangeable sodium content, nutrient deficiences, toxicities, compaction, and steep slopes.

The acidity problems encountered in the East are usually correctable by the application of dolomitic limestone, which also corrects the calcium and magnesium deficiencies. Nitrogen deficiences are corrected by either nitrogen fertilization, growth of legumes, or addition of nitrogen-containing organic residues such as manure or sewage sludge.

REVEGETATION OF MINE SPOILS

Selection of appropriate plant species is very important in developing a reclamation plan. Almost all plant species commonly produced in the East can be grown on mine spoils, but on mined areas with steep slopes, perennial vegetation is generally most effective. Although commercial forestry is possible, results indicate that mined land should first be seeded to perennial grasses and legumes and later converted to forestry.

Considerable knowledge has now been developed on the selection of suitable species for revegetation of spoils of various pH's and for revegetation of both moderate and steeply sloped areas. Likewise, much information is now available on enhancing organic content and conditioning soil with organic mulches of various types. Also, techniques have been developed for vegetating quite steep slopes (60 percent or more); for example, by creating miniature contour terraces every few feet down the slope.

In western United States, lack of plant-available water ultimately limits plant growth on reclaimed land, as it does on unmined land. Therefore, any spoil property or reclamation practice that increases infiltration or potential plant growth or reduces evaporation generally improves the efficiency of water conservation and use. Many western spoils are high in exchangeable sodium content. Results have shown that about 3 years following treatment with gypsum, up to about 50 percent of the exchangeable sodium can be displaced and leached out. Exchangeable sodium can be almost completely removed in just a few days by treatment with calcium chloride, but this treatment is expensive.

Plant-nutrient deficiences are also common in western spoils. Phosphorus is almost always deficient; however, this can be readily corrected with triple superphosphate. Biologically active organic nitrogen is often absent and must be restored through a buildup in soil organic matter. At many western mine sites, appreciable quantities of soil material are available for spreading over spoils. Results from North Dakota have shown that about 30 inches of soil material must be returned to highly sodic spoils to restore full productivity potential for commonly grown crops. However, as little as 2 inches of soil material produced yields of crested wheatgrass and native grasses equal to 50 to 70 percent of the yields obtained with 30 inches or more of soil material.

Hydrological data being accumulated indicate that the runoff and erosion potential is severe on long slopes of 9 percent or steeper. Also, preliminary data indicate that both wind and water erodibility of freshly spread soil material may be several-fold greater than that of unmined soil. Thus it appears that soil and water protection on freshly mined land is best achieved by eliminating slopes of 9 percent or steeper.

The more arid climate of the West makes the establishment of good vegetative cover more difficult than in the East. Data indicate that seedling establishment can be improved by use of various types of mulches, standing stubble, or a thin covering of soil material, gravel, or even oxidized coal if it is not too high in soluble salt content. Other research indicates that by adding small quantities of water during critical drought periods, a great deal of control can be achieved over the kinds of species established and their density. For this purpose only a few inches of water are required—a quantity often available as pit water.

The research being conducted by ARS is resulting in a technology that will protect the soil and water resources of mined areas as well as provide an economic return to the landowner. It is becoming well established that the best way to achieve these dual objectives is to establish good productive vegetative cover. Once established, this vegetation not only restricts surface water movement and erosion but, possibly of more importance, it also dries out the soil, enabling more of the precipitation received to infiltrate into the soil at the point of impact. Also, drying the soil reduces the quantity of water and the quantity of dissolved solids passing below the root zone to a water table. This, in turn, aids in controlling ground water pollution from mined areas. By revegetating, organic matter and the plant nutrients contained therein are also added to the upper surfaces of mined land, aiding in the buildup of a new soil after mining. It is apparent, then, that rapid establishment and efficient production of vegetation is one of the best defenses possible against soil and water degradation on land disturbed by mining.

COAL CLEANING

Once out of the ground, much coal needs to be "cleaned," either physically or chemically, to upgrade the quality of the coal for use and, more importantly from an environmental protection standpoint, to reduce the sulfur content so that SO_x emissions to the air are reduced during combustion. Major strategies for the control of SO_2 emissions include coal cleaning, combustion in chemically active fluidized beds, removal by flue gas scrubbing, and generation of clean synthetic fuels.

The sulfur content of coal normally ranges from less than 1 percent to more than 7 percent. Sulfur appears in coal in three forms: mineral sulfur (pyrite), organically bound sulfur, and trace quantities of "sulfate" sulfur. Sulfate sulfur is soluble in water and can be removed in wet (physical) coal preparation plants. Organic sulfur cannot be removed by physical coal preparation techniques. Pyrite occurs in sizes ranging from small discrete particles to large lumps. It can be found intimately dispersed in the coal, in bands, or in large pieces. Physical cleaning techniques are capable of removing varying fractions of the pyritic sulfur as determined by the properties of each coal. Chemical cleaning is capable of removing over 95 percent of the pyritic sulfur and up to about 70 percent of the organic sulfur as well.

SO_2 EMISSION CONTROL

Research results from EPA's R&D program on coal cleaning are described by James Kilgroe in his paper "Coal Cleaning for SO_2 Emission Control." Results indicate that, in general, pyrite removal increases with reduced particle size. This implies that to enhance pyritic sulfur removal, coal must be crushed and processed at finer particle sizes than has been the practice historically. A second finding is that the final sulfur levels to which coals can be cleaned vary across coal regions and across coal beds within the same region. Sulfur removal by chemical methods depends on coal properties and process conditions—time, pressure, temperature, and chemical reagents. Process costs will probably limit the amount of sulfur that can practicably be removed to about 95 percent of pyritic sulfur and 40 percent of organic sulfur.

The costs of physical and chemical coal cleaning for sulfur removal are uncertain. However, from correlations between ash and sulfur removal in commercial equipment, one can deduce the probable costs of sulfur removal in physical cleaning. These tentative correlations indicate that, in some cases, physical coal cleaning may be a more cost-effective emission control technique than flue gas desulfurization (FGD). However, physical cleaning is not a panacea since it cannot remove organic sulfur from coal or, in some cases, even sufficient pyritic sulfur.

Chemical cleaning costs may range from the costs of FGD to the costs of producing synthetic fuels from coal. Cost estimates for chemical coal cleaning are, however, substantially less certain than those for physical cleaning.

Removal of pyritic sulfur from steam coal by physical cleaning has not been commercially used as a method of SO_2 control. Separation at the fine-particle sizes involved, while not impossible, represents a shift to a mix of equipment and operating conditions different from those traditionally used for steam coal preparation. Dewatering and drying of larger quantities of fine coal may also be required.

Chemical coal cleaning is in the early stages of development, and it is estimated that a commercial plant could not be put into operation for at least 5 to 10 years. A number of chemical cleaning processes have been identified. However, many are only conceptual, are not presently active, have never been tested on coal, or do not result in coal-like products. Only seven or eight processes appear to merit serious consideration at this time. A report on the status of each of these processes will soon be published.

PHYSICAL CLEANING PROCESSES

Physical cleaning can be used on a limited number of U.S. coals to meet Federal New Source Performance Standards (NSPS) for steam generators. Moreover, a larger number of coals can be physically cleaned (1) to meet less stringent State SO_2 emission standards or (2) in conjunction with flue gas desulfurization (FGD) to lower emission control costs. The number of coals that could be cleaned to NSPS levels could be increased by either a reduction in the coal particle size or a reduction in the Btu recovery value of the cleaned product. In the latter case, the reject coal could probably be used in a boiler with FGD.

Mr. Kilgroe also describes how by combining physical coal cleaning and flue gas desulfurization, the advantages of each technique can be used to minimize emission control costs. One recent study has shown significant economic advantages to this combined pollution control method. In 36 case studies where allowable SO_2 emissions varied from 1.2 to 1.6 pounds $SO_2/10_6$ Btu, the cost of using a combination of *conventional* coal cleaning and flue gas desulfurization was 2 percent to 55 percent lower than flue gas desulfurization alone for new plants and 10 percent to 60 percent lower for existing plants. The arithmetic average for the cases cited showed costs about 30 percent lower for new plants and 40 percent lower for existing plants.

COAL CONTAMINANTS

The overall objectives of EPA's work on environmental assessment have been to characterize coal contaminants and to identify the fate of these contaminants during coal processing and coal use. Research on the occurrence and distribution of trace elements in coal has yielded the following conclusions.

- Elemental concentrations tend to be highest in coals from the Appalachians, lowest in coals from the western United States, and intermediate in coals from the Illinois Basin.

- Elements with the largest ranges in concentration are found in distinct mineral phases in coal; elements with narrow ranges are found in organic combination in coal.

- Only four elements (boron, chlorine, selenium, and arsenic) are, on the average, present in coals in concentrations significantly greater than the average concentrations in the earth's crust.

- Benches of a single coal seam often exhibit wide variations in concentrations of elements. High concentrations are most commonly observed at the top and/or bottom of the coal seam.

- Major quantities of elements with high inorganic affinities may be removed from coals by specific-gravity cleaning techniques. Disposal of these residue materials may, in turn, pose a significant environmental problem.

COAL WASTES FROM PLANTS

Other studies have concentrated on coal wastes from four preparation plants. Trace elements and minerals in these wastes were identified. Associations were established between the trace elements and the major minerals present. Laboratory leaching studies simulating environmental weathering have shown that leaching increased with decreased pH and with increased availability of air, increased surface area, and increased time. The highly leachable elements were determined.

Experiments have been conducted to evaluate sulfur and trace element emissions from the combustion of coals treated by the Battelle Hydrothermal Process. During combustion, from 25 percent to 75 percent of the fuel sulfur was retained in the combustor ash and fly ash. Generally, ash sulfur retention in coals leached with both NaOH and $Ca(OH)_2$ was superior to that in the NaOH-treated coals. For untreated coals, sulfur retention ranged from 3 percent to 30 percent. Emission of trace elements from combustion of treated coals was also substantially reduced as compared with corresponding combustion projects from the raw coals.

VARIABILITY OF CONTAMINANTS WITH COAL SEAMS

A USGS project on variability of contaminants with coal seams has the following objectives:

- To determine the geologic factors controlling lateral and vertical variations, crystal form, and size of pyrite inclusions
- To determine the geologic factors controlling mineral and elemental variations in coal
- To evaluate various methods for correlating cleanability with coal petrologic characteristics
- To develop methodology for determining the cleanability of various seams of coal.

In the development of coal-cleaning technology, a major 3-year project to assess technology for the physical and chemical desulfurization of coal was begun in January 1977. Its objective is to determine the performance and cost of commercial coal-cleaning equipment in separating fine coal and pyrite. Similar cost and performance evaluations will be made on equipment for dewatering and drying fine coal. Other project activities include evaluation of chemical coal cleaning processes, evaluation of coal preparation requirements for synthetic fuel conversion processes, evaluation of pollution control technology for coal cleaning, and engineering trade-off studies to establish the performance and costs of coal preparation plants designed for improved pyrite removal and Btu recovery.

OBJECTIVES OF MAJOR DEMONSTRATION PROGRAM

The objectives of a major demonstration program are to:

- Determine the variability of sulfur and other pollutants in the feed coal
- Determine the performance of separation equipment
- Determine the capability of process controls to maintain product specifications
- Characterize pollutant streams
- Evaluate the effects of cleaned coal on power plant performance
- Evaluate the effectiveness of residue disposal techniques
- Determine the fate of various minor and trace pollutants
- Determine capital and operating costs of coal preparation and power plants
- Evaluate other equipment or coal-cleaning circuits, as needed, to demonstrate the viability of cleaning coal to meet SO_2 emission regulations.

The preparation plant is scheduled to begin start-up tests late this spring. Pilot plant tests are already underway.

Coal desulfurization by aqueous ferric salt leaching is capable of removing from 90 to 95 percent of the sulfur in a variety of U.S. coals. Construction of a 1/3-ton-per-hour reactor test unit has been completed. Initial test runs are planned for August. An initial 9-month test program is planned to verify major process variables.

A thermochemical process for coal desulfurization is capable of removing both organic and pyritic sulfur from coal. The principal achievement to date has been the validation of the process concept. Operating conditions have been determined, with both laboratory- and bench-scale equipment. Tests showing satisfactory desulfurization of four coals have been completed. In each case the treated product could be burned without exceeding present NSPS for SO_2 emissions. Achievement of satisfactory desulfurization was the result of a research breakthrough in coal treatment. It was discovered that mild, oxidative pretreatment of the coal rendered the organic sulfur more amenable to removal; until this discovery, sulfur removal had been unsatisfactory. It now appears that this system may be a viable alternative for making a low-sulfur, solid fossil fuel from those U.S. coals that cannot now be directly consumed without severe environmental impact.

Laboratory experiments have demonstrated the technical feasibility of coal desulfurization by microwave energy. Both pyritic and organic sulfur appear to be

energy
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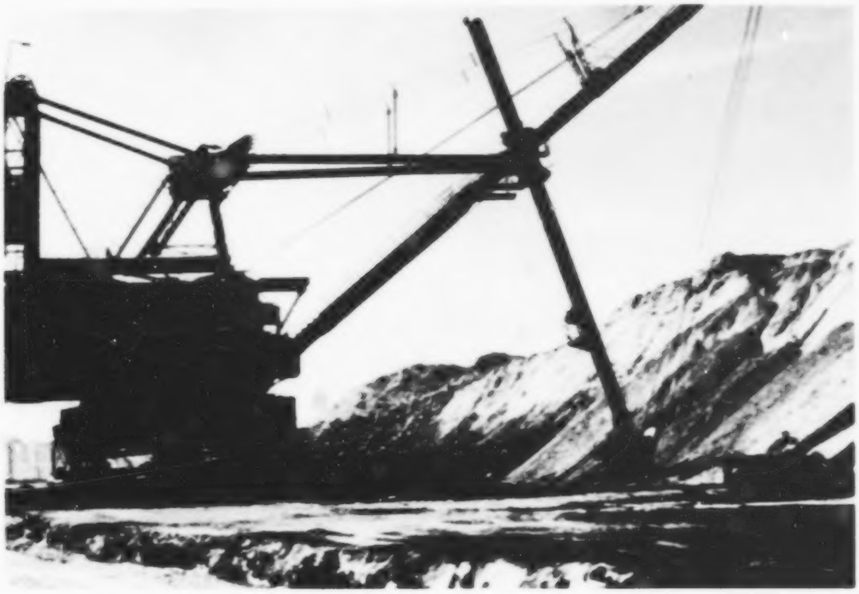
removed. Pyrite is preferentially excited by the microwave energy, producing volatile or water-soluble compounds that may be washed from the coal. Laboratory work continues to evaluate the mechanisms of desulfurization and to identify the process variables that affect sulfur removal.

SULFUR REDUCTION POTENTIAL

The U.S. Bureau of Mines program has been described in a paper by Richard Hucko and Albert Deurbrouck. Both in-house and contract projects are included within the USBM program. One long-term in-house project is aimed at determining the forms of sulfur in the major sources of utility steam coals and the washabilities of these coals. This information is necessary to assess the impact that physical coal cleaning will have on the level of sulfur oxide emissions from stationary combustion sources. The latest publication, "Sulfur Reduction Potential of U.S. Coals," covers work performed from 1965 to mid-1974 and presents the results of washability studies of 455 raw coal channel samples collected from 6 coal-producing regions of the U.S. Only 14 percent of raw coal samples could meet the new source SO_2 emission standard of 1.2 pounds $SO_2/10^6$ Btu. Twenty-four percent of the samples would meet the standard at a 90 percent Btu recovery when crushed to 1½ inches top size, while 32 percent would meet the standard at a Btu recovery of 50 percent when crushed to 14-mesh top size.



A central coal preparation process development facility is to be constructed in the near future at Bruceton, Pennsylvania. Engineering data for scale-up to full-size commercial coal preparation plant operation will be developed. The pilot plant section of the proposed facility will have a nominal capacity of 10 to 25 tons per hour of raw coal, depending on the flow scheme used; process flexibility was a prime design requisite. The facility will also contain an area for bench-scale work. Construction of the facility should begin before the end of calendar year 1977.

COAL-PYRITE FLOTATION

A test program to demonstrate the commercial feasibility of the Coal-Pyrite Flotation Process is about to begin. The process involves the depression of coal with a hydrophilic colloidal substance while the coal-pyrite is floated with a sulfhydryl collector. The process has been tested and proved effective at pilot plant scale. Construction of the full-scale facility should be finished by August 1977. Flotation tests will then be run for about 1 year, after which test results will be evaluated.

Research is being conducted on the depressant and collector adsorption reactions which occur during coal desulfurization by the Coal-Pyrite Flotation Process. This project will determine whether primary pyrite flotation followed by a second-stage coal flotation is feasible. Such a process would produce a final clean coal product in thickened form ready for dewatering. The effect of residual reagent in plant recyle water will also be determined. Specific objectives are to:

- Identify and characterize the hydrophilic polymeric coal depressants

- Determine the important operating variables that control the adsorption-desorption reactions
- Establish procedures to allow in-plant water recycle.

It has already been found that several reagents in excess of 1 mg/l of coal slurry depress at least 80 percent of the coal. Desorption of the depressants from the coal surface was found to be difficult, and the adsorption reaction appears to be irreversible. However, the depressed coal can be reactivated and floated by the addition of neutral molecular oil. Bench-scale coal flotation experiments are now being conducted to find optimum conditions to depress coal particles and float pyrite. During these flotation tests, the residual depressant concentration will be measured and water recycle experiments will be done to determine the effect on subsequent coal flotation.

HIGH GRADIENT MAGNETIC SEPARATION

Another project is attempting to establish the technical feasibility of removing inorganic sulfur from dry coal powders at commercially significant processing rates by high gradient magnetic separation (HGMS). Reduction of sulfur by HGMS could permit the direct combustion of large coal reserves east of the Mississippi River which have a high percentage of pyritic sulfur but are low in organic sulfur. Initial testing with slurries has shown significant reductions in both pyritic sulfur and ash. Dry separation test results show some magnetic separation—although it is much smaller than that in the case of water slurries—and no significant trend in sulfur or ash removal with changes in applied magnetic field or in flow velocity or with change from an expanded metal to a steel wool matrix.

During beneficiation, rotary vacuum filters are relatively economical and practical devices for dewatering froth flotation concentrates and flocculated slurries, but the product usually retains more than 20 percent moisture. As a result, thermal drying is often required to reduce the moisture content to an acceptable level. To improve mechanical methods for dewatering fine coal, work is also being conducted to characterize the dewatering of fine-size coal, to determine the effect of an electric field on the dewatering process, to determine the influence that slurry pH has on dewatering, and to assess the influence of selected chemical additives on moisture retained in filter cakes. To date, test data on the effects of various cationic, anionic, and nonionic surfactants have been used to formulate a model for surfactant behavior in a cake of fine-size coal and to determine its effect on the dewatering of coal.

BLACKWATER FLOCCULATION

Treatment of black waters from coal preparation plants is complicated by their heterogeneous nature and by lack of information on the behavior of relatively simple systems. Laboratory investigation of black water flocculation is being carried out. The interrelation of flocculation rate, settling rate, and sludge volume is being evaluated to establish a technique for producing as dense a sludge as possible in a thickener operating at the highest possible rate. Further, the results of studies on the flocculation of heterogeneous systems will be used to develop mathematical models simulating the flocculation of particles in practical systems. The composition and particle-size distribution have been determined on black water samples from a number of preparation plants. The chemical and physical characteristics of samples from the eastern and interior areas are essentially the same. Samples from western operations appear to have somewhat different characteristics.

COMPUTER SIMULATION PROGRAM

A computer simulation program for coal preparation is being developed. Included in the program are performance data for each of the commonly used coal washing devices. The program also includes mathematical modeling of crushers, screens, dewatering equipment, dryers, and thickeners. It can be used to predict the performance of a given plant configuration and set of operating conditions or to determine the operating conditions which will give a specified ash and pyritic sulfur reduction for a given plant configuration.

Next, dewatering devices, impurity liberation upon crushing, and an economic subroutine will be simulated, thus making possible rational choices of alternate circuits for ash and sulfur reduction based on reliable engineering data and overall capital and operating economics.

ECONOMIC EVALUATION

The economic potential of coal preparation in combination with stack gas scrubbing has been evaluated. Generally speaking, of the various methods for removing sulfur, the physical removal of pyritic sulfur is the lowest-cost technology and the most widely applied. However, a number of coals cannot meet new-source sulfur emission standards in this way. In these studies, an economic evaluation has been made of the cost of a new utility plant exclusively removing SO_2 by stack gas scrubbing. This was followed by a similar evaluation of the use of physical coal cleaning and stack gas scrubbing combined to attain the same sulfur emission level. The study concluded that, in general, the combination of coal preparation and stack gas scrubbing was less expensive than scrubbing alone.

CHEMICAL CLEANING

In another study, six chemical cleaning processes were analyzed. Process flow charts were drawn for each process and analyzed in terms of cost and sulfur removal performance. While none of the processes is economically competitive with physical cleaning, oxidative desulfurization shows the most promise from the viewpoint of operability and cost.

TRACE ELEMENT CONTENT

A coal washability study has been completed, showing the trace element content of various specific gravity fractions for coal samples from various coal producing regions. Most of the trace elements of interest concentrate in the heavier specific gravity fractions of the coal, indicating that they are associated with mineral matter and that removal of this material would result in significant trace element reductions, ranging up to 88 percent.

This summary presents the highlights of the ongoing interagency R&D effort on mining and beneficiation. Much more comprehensive information is presented in the detailed papers prepared by the participating agencies.

DAVID G. STEPHAN

B.S., M.S., and Ph.D., Chemical Engineering, Ohio State Engineering. Experience in research and development of problems of air and water pollution and in pollution control methods in municipal and industrial wastes. Internationally known for work in water pollution in areas of advanced waste treatment and water renovation. Held top level posts with U.S. Public Health Service, i.e., Head of Air Pollution Control Equipment Research Program; Deputy Chief, Advanced Waste Treatment Research Program; Deputy Chief, Basic and Applied Sciences Branch of Division of Water Supply and Pollution Control. Was Director of Research Federal Water Pollution Control Administration. When EPA was formed, served as Assistant Commissioner for Research and Development in Water Quality Office. Presently, Director, Industrial Environmental Research Laboratory, EPA, Cincinnati, OH.

questions & answers

extraction and beneficiation

Mr. Stewart Lyons
Michigan United Conservation Club

Dr. Edward S. Rubin
Carnegie-Mellon University

Mr. Marvin C. Gage
San Francisco, California

Mr. Nathan Sauberman
Retired Consulting Engineer

Mr. R. K. Bose
Association of American Railroads

QUESTION: You alluded to using fly ash as part of the reclamation process in strip mining. Other than bulk, is there any use or any other positive effect that comes from fly ash?

RESPONSE: Dr. James P. Power (USDA)

The fly ash is not just fly ash. First, we have to know the chemical composition of the fly ash. Especially in the western coals, much of the fly ash is relatively high in soluble salts, which almost precludes its use in any reclamation scheme for revegetation. Fly ash of that nature has to be buried beyond the root zone so it will not interfere with vegetation or be disposed of.

In the East or in areas where the salinity problem is not so severe, there are situations where the use of fly ash may be beneficial in the revegetation process, particularly in physical conditioning of the soil. In areas with a high clay content, it may help to alleviate some of the physical problems associated with that.

QUESTION:

I would like to direct two questions to Mr. Kilgroe. The first regards nitrogen in coal. We heard here that the future NO_x problem is the sleeper relative to SO_2 in particulates. I am aware that, in processes like solvent refining of coal, the coal nitrogen is concentrated in the fuel. My first question is what happens to the nitrogen in the chemical coal cleaning processes?

RESPONSE: Mr. James D. Kilgroe (EPA)

Most of the nitrogen is concentrated throughout the organic fraction, and physical cleaning does not affect the nitrogen level.

We are going to study about what happens to nitrogen in the chemical coal cleaning processes because in the past we have been myopic in studying only sulfur dioxides. We are, however, starting to look at all the other pollutants which are contained in coal.

QUESTION:

My second question regards using the waste coal in low Btu recovery with fine crushing for boilers fired by or equipped with FGD. I presume we would be talking about waste coal with a relatively low heating value. Is anyone implementing this concept?

RESPONSE: Mr. Kilgroe

At Homer City, we are taking a coal preparation plant and producing a multistream coal product in which we have one product that will meet new source performance standards, which are 1.2 pounds per million Btu. In other instances, we are taking a product of coal that will meet a state standard of 4 pounds per million Btu. In the past we have looked at the strategy of using some of the waste product for our high sulfur combustor. We have looked at various combustors that would use 40 percent ash and 10 percent sulfur. As yet, due to funding limitations, we have not gotten into any pilot-type studies or any laboratory studies. However, if coal prices continue to increase, that process should become economically viable.

QUESTION:

About a year ago, I saw a film on strip mining distribution by an anti-strip mining group in Montana, indicating that as the shallow acquifers were disturbed in strip mining operations, there was a homogeneous mixture when soil was reapplied. In fact, permeability was so great that native grasses could not maintain themselves under normal rainfall. Is that a true statement and, if so, is there a mitigating measure involved in revegetation?

RESPONSE: Mr. Grant Davis (USDA)

It would depend on the physical and chemical characteristics of the spoil. However, in most recent mining cases where careful practices have been followed, vegetation has been easily established in most instances in Montana and surrounding states.

Permeability is a problem especially where we have high sodium spoils and need enough soil cover to establish vegetation.

RESPONSE: Mr. John Martin (EPA)

We have heard the same comment from many people concerning the revegetation of the western spoils, especially in light of the new legislation and the question about alluvial valleys, if we can ever define those. We are also analyzing the characteristics of the soil to determine consistency and reclamation possibilities. So, we are addressing the idea of porosity and how much density you can get in replaced spoils.

QUESTION:

Can you give me further information about the extent of our uranium resouces, as some of the leaching problems of uranium that you touched on, and some of the radiological problems of uranium and the tailings that are the result of milling and mining?

RESPONSE: Mr. Martin

We have only had a very small amount of support in uranium mining and milling in the past years. It has been the smallest and the newest program from the extraction technology branch of EPA. That is why there is very little activity in that area to date.

QUESTION:

I am disappointed because EPA is intimately involved along with ERDA, not in a regulatory matter but as an advisor to the program, and it seems to me that EPA is hanging back on this. Is it, or am I mistaken?

COMMENT: Dr. David G. Stephan (EPA)

Perhaps I can comment on that in terms of the overall program with regard to radiological wastes. EPA shares responsibility with the Nuclear Regulatory Commission in the radiological area. EPA has responsibility dealing with the environmental ambient standards for various radiological pollutants, and the Nuclear Regulatory Commission has responsibility in the emissions standards area.

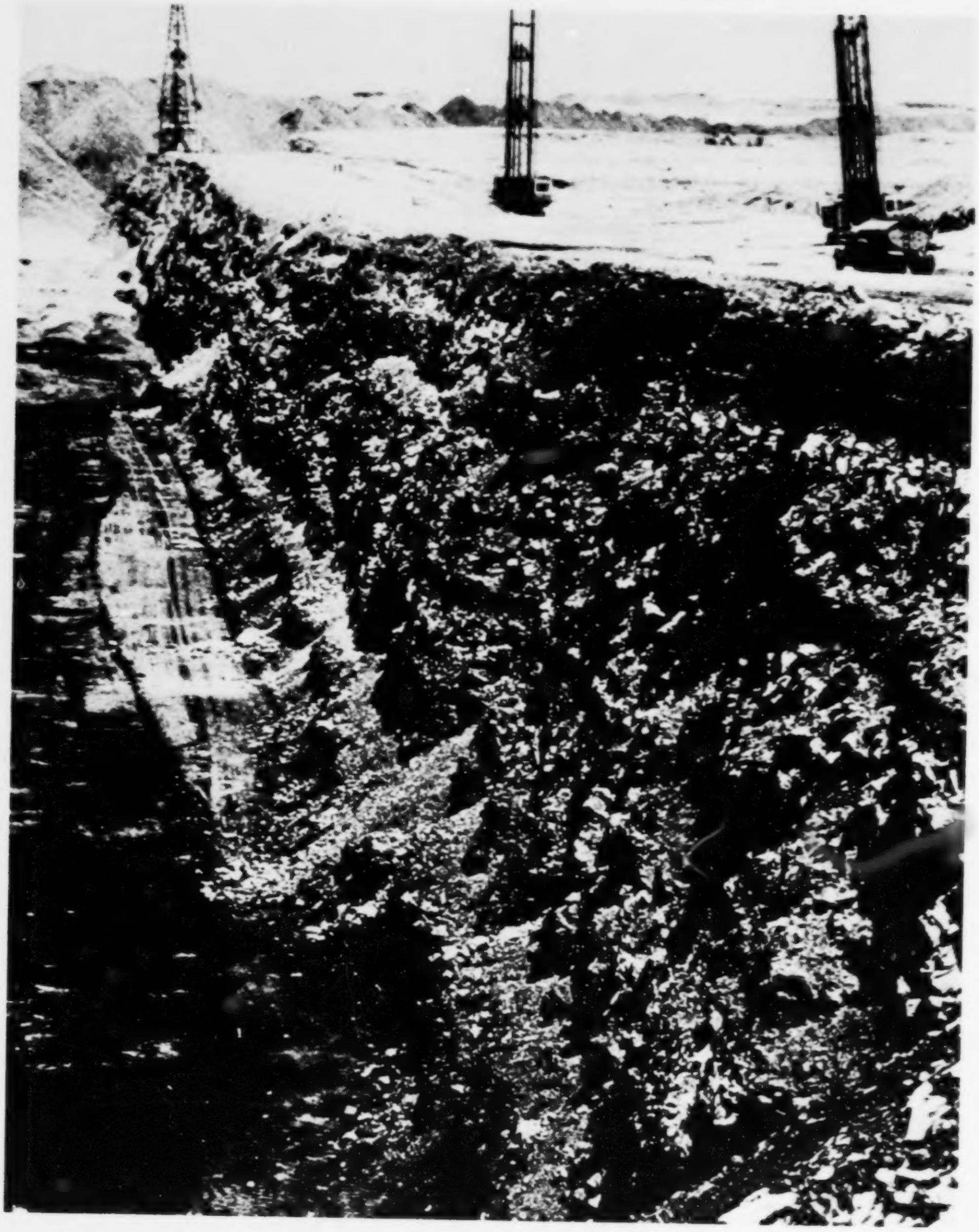
We have begun work with regard to uranium mining, but that work is very limited in scope at the present time. I hope that, due to the enhanced concern for nuclear power, which we heard discussed recently, our work will be somewhat increased in the area. Obviously there are going to be strong needs there, and we know very little about the mining and milling operations and the environmental impact, particularly this *in situ* leaching operation. As far as I know, there is almost no knowledge of what impact that can have, either on ground waters or on surface waters near the site.

First, what is the impact of the boron and the arsenic and other minerals that you said are going to be liberated from the coal crushings on the environmental impact of the water slurry that will be developed?

RESPONSE: Mr. Kilgroe

I admit to a great deal of ignorance on the subject of slurry pipelines. We have an environmental assessment program which is just getting started and one of the areas of study is the transportation of coal. We have had some studies with the Los Alamos Scientific Laboratories in which we have studied the leaching of various trace elements from coal preparation plant wastes. As alluded to earlier in the discussions of acid mine drainage, it is a direct function of the acidity, the size of the material. So our leaching studies indicated that if we have very high pyrite coal and very finely divided coal and if we also have the alternate cycling of, say, air and water through the waste, we can then potentially leach out a lot of the trace elements such as arsenic and cadmium in the waste.

This is about as far as we have come to date on the studies. We are concerned about this type of problem. Typically, however, the western coals have a smaller fraction of pyritic sulfur; most of the sulfur in the western coals is organic, so that problem is reduced significantly just because of the form of the sulfur in the coal itself. We speculate that the leaching out of trace elements may be somewhat reduced in the pipeline.



QUESTION:

Second, was the energy that is involved in the crushing of coal of a sufficiently finer mesh to have it float on the water slurry pipelines? Could you give us an idea as to what kind of energy requirements are required?

RESPONSE: Mr. Kilgroe

Well, certainly no higher energy requirements than a pulverized coal-firing boiler, as I do not believe the size distribution is as fine as pulverizing the coal for firing. Probably as great a problem would be the energy requirements for de-watering and drying the coal once we get it to the use source. I suspect that de-watering and drying rather than crushing is where our largest energy demand will be.

QUESTION:

Mr. Martin, do you know the timing on the study evaluating the five different transport concepts? Is that just under way?

RESPONSE: Mr. Martin

It is just finishing. We do have figures for the energy requirements of the various modes of transportation, one being the pipeline, and I believe incorporated in that study are the requirements for crushing, pumping, and de-watering. I cannot give you the figures right now, but I know we do have the study just being completed.

QUESTION:

My question is directed to the gentlemen from USDA. You have mentioned selenium as a trace contaminant coming from coal. The toxicity of selenium is due to its entry in the food chain as an analog of sulfur and, in general, it is toxic at above 1 percent of the sulfur concentration.

I was wondering the following: (1) what is the proportion of selenium in the coal and (2) do the desulfurization procedures effectively remove the selenium?

RESPONSE: Dr. Power

There are many different trace elements we looked at, and selenium is probably associated with the mineral matter in the coal being removed during physical cleaning. In that respect it may pose a problem in disposal of residue, but I am not sure what the exact concentrations would be. They would vary significantly with the individual coals that you are concerned with.

QUESTION:

Reference has been made to planting strip mine banks in the eastern United States. I have a potential problem in West Virginia and would like to have a reference on how to come out with the best solution possible.

RESPONSE: Mr. Martin

I might give you a couple of ideas, at least where to look for something in our shop. We have one manual, which is now a couple years old, on environmental protection in surface mining of coal by Elmore Grimm. It is a general manual on surface mining, but it does touch on revegetation. We have a couple of others dealing with the revegetation aspects in Kentucky and in northern West Virginia. We have those publications available at our office. You may write and ask for them simply by naming the subject of revegetation.

COMMENT: Mr. Davis

The Forest Service has an office in Princeton, West Virginia, that can help you on specific questions. The Soil Conversation Service also has a planting guide for strip mine spoils for West Virginia; you may get information from there. The Soil Conservation Districts in West Virginia also help with the planting, and you can contact your local district man for help.

QUESTION:

One of the papers hinted at the potential fine coal processing for releasing additional impurities, and I would like to ask whether or not any programs exist in the area of ultrafine coal grinding and the removal of the impurities once they are released?

RESPONSE: Mr. Kilgroe

We are continuing our cleanability studies with the U.S. Bureau of Mines, and we are looking at various trace elements, fractions and the specific gravity fractions of various size distributions of crushed coal. The U.S. Geological Survey and the Illinois Geological Survey are also continuing to look at the distribution of the trace elements as a function of size distribution. But, we have not really gotten down to the fine grinding of coal yet. We are still talking in the range of 28 mesh, and I assume by fine grinding you might be talking about a minus 328 mesh similar to the pulverized coal or that for a utility boiler.

RESPONSE: Mr. Richard Hucko (U.S. Bureau of Mines)

Yes, I might just add one other thing to that. In the 455 samples that were reported on as part of the U.S. Bureau of Mines washability study, which of course is the work funded by Mr. Kilgroe through EPA, the coals were crushed to 1 1/2 inches, 3/8 inch, and 14 mesh top size. There is a part of that sample for each single coal that we did that still remains, and they are going to be crushed to 100 and perhaps 200 mesh and evaluated similarly to the way they were evaluated for the larger sizes. So that may help answer some of the questions that have been raised.

technical discussion

RESEARCH AND DEVELOPMENT PROGRAMS FOR POLLUTION CONTROL IN MINING AND TRANSPORT OF SOLID FUELS

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INTRODUCTION

Mining activities of one type or another have an impact on every region of the United States. The pollution problems associated with extraction and transport of mineral resources are likewise of national concern. The U. S. Environmental Protection Agency (EPA) is directing a significant research and development program aimed at the ultimate control and elimination of these pollution problems. At the same time, production levels for raw materials and fuels must not drop so that individual welfare and national security are threatened.

As mandated under the water, air, and solid waste acts, the Extraction Technology Branch (ETB), Industrial Environmental Research Laboratory, EPA, is working to develop and prove new pollution control technology for production of both solid fossil fuels and some nonfuel minerals. Work is progressing to: (1) assess the potential environmental damages (air, water, noise levels, etc.) from active and abandoned mining, transporting, and beneficiation processes; (2) develop methods to control, treat, and abate environmental pollutants in these operations; (3) demonstrate and document the technical/operational feasibility and cost-effectiveness of environmental control options; (4) provide, on a timely basis, environmental control criteria; and (5) prepare standardized user manuals that encompass all environmental pollution control aspects to meet the operational needs of regulatory and control agencies and the mining industry.

The past emphasis of predecessors of ETB was on large-scale demonstration of pollution control for abandoned coal mines. The Elkins Demonstration Project (currently being updated) was the first of its type to document the effects of surface mine reclamation and underground mine sealing throughout an entire watershed. Although the project was modified to accommodate continued activity in the mines, it proved that properly planned reclamation could be effective in reducing the production of acid mine drainage (AMD). Subsequent research efforts through the late 1960's were oriented toward various aspects of AMD treatment by neutralization techniques, reverse osmosis, ion exchange, freezing, and foam fractionation. Other programs were initiated to develop control technology for eastern coal mines to reduce water pollution and enhance the success of reclamation efforts.

EPA's efforts to develop control technology through research and demonstration projects shifted slightly in 1975. Work statements and final reports were to be oriented more toward production of user manuals. In addition, studies were to be directed toward assessment of all media pollution problems associated with energy- and nonenergy-related extraction.

Active work areas for ETB are presently divided into two sections--energy production and materials production. The following discussion will deal only with energy-related research, including that for surface and underground eastern coal mines, treatment of mine drainage, oil shale mining, uranium mining, and transport of solid fuels. Although the intent of the program is development and demonstration of total pollution control technology, individual projects may concentrate on one or more aspects of pollution control such as abatement of AMD, soil stabilization and revegetation, moisture conservation, dust control, or solid waste disposal.

TECHNICAL PROGRAMS

Eastern Surface Coal Mines

In the past, surface mines often resulted in barren, ungraded spoil piles surrounding abandoned pits or produced long barren scars in the mountainous regions where contour highwalls were left to stand above loose and eroded spoil cast down the mountainside. Growing environmental concern and more stringent state mining regulations combined to yield sites that were reclaimed, with varying degrees of success, and returned to some useful, or at least stable, form. Even considering the newer theories of backfilling, highwall reduction, etc., many of the steeper mountainous regions were environmentally unsuited for conventional contour mining technologies. Newly developed mining techniques--involving block cutting, haulback of spoils, mountaintop removal, and hollow fills--have appeared within the past few years. These techniques offer the advantage of containing spoils in specifically engineered sites to reduce greatly the hazards of massive landslides, erosion, and stream siltation.

The most recently initiated programs of ETB in this area involve development of proper premine planning practices, assessment of the environmental impact of newly emerging extraction technologies, and demonstration of controls for minimizing off-site damages. A minor effort is continuing in reclamation research to keep abreast of current practice. The grant to Pennsylvania State University to prepare a "Manual for Premining Planning Eastern Surface Coal Mines" is a major effort to define the role of proper planning in reducing environmental damages. Two projects--to study the control of surface mine sedimentation through block-cut mining and to assess the mountaintop removal and head of hollow fill mining techniques--are characteristic of ETB efforts in

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developing more advanced pollution control technology. An active project to demonstrate sediment control techniques for haul roads is currently progressing with equal funding from EPA and the Bureau of Mines. Through this cooperative grant to the Commonwealth of Kentucky, both agencies hope to prove that current haul road construction technology, properly applied, can effectively reduce pollution contributions from a major source of suspended solids in the mine area. Other interagency projects relating to eastern surface mines involve the Tennessee Valley Authority (TVA)--"Strip Mine Drainage Water Quality" and "Ecological Recovery after Reclamation of Toxic Spoils"--and the U. S. Department of Agriculture (USDA)--"Controlling Adverse Effects of Mining." In addition, EPA is cooperating with the Energy Research and Development Administration (ERDA) in a study to characterize the wastes and waste streams at 20 mine sites throughout the country.

The above projects illustrate the types of effort involved in the EPA mining program. There are numerous other research and development projects that will supply information to the premining planning manual or subsequent user manuals for environmental control of surface mines.

Eastern Underground Coal Mines

Underground coal operations are a major source of mining pollution in the eastern United States (east of the 100th meridian). During and following mining, water drains or is pumped from the mine complex. The quality of this effluent is highly variable, depending on the seam mined, mining method, type of mine, and water control techniques applied. Surface disturbances associated with underground mines contribute both to the sediment load of surface runoff and to the load of windblown particulate matter.

Mine drainage treatment and mine sealing have long been the accepted methods for abatement of this pollution. Each, however, has its disadvantages. The treatment process is quite acceptable for active operations, but is very expensive and at best a short-term cure. After a mine is closed, water treatment must continue for years. Mine sealing is not a miracle cure for mine drainage in that it is successful only in special cases with ideal conditions. Air sealing to prevent oxidation of acid-forming materials has proved to be nearly impossible.

The emphasis that EPA has placed on control of underground mine drainage, for the past several years, is oriented toward at-source control. How can mines be developed, operated, and closed with a minimum of environmental damage or required water treatment? The "Deer Park Daylighting Project," currently in the demonstration phase, is an attempt to surface mine and then reclaim a previously mined area in northwestern Maryland. The grant is intended to show that it is feasible, from an energy and environmental standpoint, to strip out an abandoned underground mine, recover the unmined coal pillars, and restore the area to a state of productivity.

A different type of project in Pennsylvania is investigating the "Cost Effectiveness of Aquifer Dewatering." The thrust of the work is to show that mine drainage can be reduced by artificially removing or intercepting the groundwater in the vicinity of the mine; thus reducing the infiltration to the mine void. Other projects are proceeding to investigate the effectiveness of backfilling mine voids with waste materials, to define and reduce water infiltration to the mine workings, to define the mine's effect on surrounding groundwater resources, and to develop more effective mine sealing techniques.

Treatment of Mine Drainage

For many years, treatment techniques for mine drainage have involved a settling system coupled with simple neutralization of acid waters. Neutralizing agents such as limestone, lime, soda ash, and caustic soda have been used extensively in the acid-producing eastern coal fields. Processes involving lime neutralization are probably the most advanced and proven. Recent trends have also shown that combinations of neutralizing agents commonly have a more desirable treatment effect than the same agents used separately. As an example, recent EPA studies have involved the use of limestone/lime neutralization techniques, finding them to be efficient, less expensive from an operating standpoint, and capable of producing denser floc material for the settling stage than the technique of using lime alone.

The current role of ETB is to redefine the applicability of current treatment technology to mining situations other than the eastern coal fields. In addition, work is continuing to develop and demonstrate more advanced treatment techniques such as ion exchange, reverse osmosis, neutrolosis, etc. To illustrate the current research trends, one active project entitled "Purification of Acid Mine Drainage by Neutrolosis" has as its objective the development of a refined and more efficient system for reverse osmosis treatment of acid drainage using lime neutralization of the resultant brines.

Coupled with the various projects involved in removing acid, metal ions, sediment, and other impurities, are efforts for safe disposal techniques for the sludges and brines that are the by-products of the neutralization process. Current studies have just begun involving sludge dewatering, lagooning, and spray irrigation.

Western Coal Mining

As a part of its mining research program, EPA has the responsibility to minimize environmental damages due to the rapid increase in the production of western coal. In order to meet this responsibility, the actual and/or potential pollutants must be determined and control technology developed. In addition to grading, surface water control, erosion protection, and revegetation work--as required for eastern surface coal mines--the western mines personnel must make provision for severe drought conditions, wind erosion and high-intensity rain storms. Many of the active western mines are open pit operations that have the potential for major aquifer disruption and extremely difficult reclamation. Current technology for the prevention and control of pollution involves revegetation and control of surface and subsurface waters where possible.

Because ETB programs in western coal mining are relatively new, it is vital that a large portion of the programs deal with assessment of potential impacts and problem areas. To this end, the "Northern Cheyenne Tribal Council Project," for example, involves the impacts that mine development on the reservation would have on groundwater, surface water, land use, and socioeconomic structures. EPA and the Tribal Council hope to develop a plan for the Reservation that would delineate environmentally fragile areas and allow for selective mining to benefit the Northern Cheyenne people while not destroying their customs and heritage.

Work is also progressing on active mine sites, as in the project in Arizona for "Environmental Monitoring in the Four Corners Area." Here, information on revegetation establishment, surface water quality, groundwater quality and quantities, and irrigation potentials is being collected from the spoil material of the mine site. In the same area, the Bureau of Mines and ERDA are collecting complementary data regarding reclamation practices and water harvesting techniques.

Studies of the groundwater formations in the coal producing area of the West and development of seed sources and planting techniques are not specifically functions of EPA. They are, however, being conducted by the U. S. Geological Survey (USGS) and USDA. These studies are vital in understanding the total regional environment and are beneficial sources of information for EPA's site studies.

Transport of Solid Fuels

The objective of this new work of ETB is to produce a multimedia assessment of the current environmental problems and of any technology needed to minimize the pollutional aspects of solid fuel transport. After relevant research and development work, a comparison and evaluation of various control techniques will be made available to government and industry in the form of a user manual. Here the economics and effectiveness of the various control options of each mode of transport will be thoroughly discussed to provide the user with a basis for selecting or evaluating a sound system for moving energy-producing materials. The work area deals with the five basic modes of transport in general use by the coal industry: truck, rail, barge, pipeline, and conveyor.

A current study relating to the above work is entitled "The Environmental and Pollution Aspects of Coal Slurry Pipelines." Here, the ETB hopes to define various problem areas of the pipeline approach so that future efforts can be focused on solving them.

Uranium Extraction

The mining of uranium entails a sizeable variety of environmental hazards including surface and groundwater contamination, fugitive dust emissions, and solid waste disposal problems created by onsite beneficiation processes. To date, little effective control technology is available. The existing state-of-the-art for mining control technology needs to be assessed, as does the possibility of transfer or adaptation of technology from similar extractive industries.

In addition to being extracted by surface and conventional underground mining techniques, uranium is obtained by in situ underground processes. There is at present little understanding of the geologic and hydrologic setting in which this type of extraction can occur. The impact of solvents utilized in the leaching process is not well known. A need exists for the determination and translation of this information for use in evaluating the environmental impact of in situ uranium extraction.

Currently under consideration are three projects for beginning the collection of data necessary to evaluate the above mentioned extractive techniques. This information, to be partially assembled as a "User Manual," should provide a basis for continuing and effective research and development efforts to reduce or control environmental damages resulting from uranium extraction.

PROGRAM ACCOMPLISHMENTS

During the past year, various final reports have been released by ETB as products of the mining research program. These publications, in the form of research reports or user manuals, represent completed efforts. In many cases these results will be referenced and incorporated in future manuals that will summarize all work undertaken in a given subject area (i.e., Eastern Surface Coal Mines, etc.). Present reports have received wide distribution throughout industry and government, and are being used to design control systems or provide information regarding specific problem areas or designs. The manual entitled "Erosion and Sediment Control" has received extremely good distribution (over 15,000 copies) and is being used by many engineers, mining companies, and state and federal agencies for design and evaluation of sediment control structures. Other final reports are as follows:

1. "Trough Creek Limestone Barrier Installation and Evaluation," EPA-600/2-76-114--a demonstration project to neutralize an acid stream in place, using porous limestone barriers.
2. "Extensive Overburden Potentials for Soil and Water Quality," EPA-600/2-76-184--a manual for the use of overburden sampling and analysis to aid in premining planning.
3. "Evaluation of Surface Mine Reclamation Techniques - Campbell's Run Watershed, Pennsylvania," EPA-600/2-76-111--a

demonstration of reclamation of 21 hectares of strip mined land to reduce infiltration to underground workings.

4. "Effectiveness of Surface Mine Sedimentation Ponds," EPA-600/2-76-117--a survey of mine sediment structures to determine efficiency of removal of suspended solids.

5. "Treatment of Acid Mine Drainage by the Alumina-Lime-Soda Process," EPA-600/2-76-206--a bench scale study to produce potentially potable quality water from AMD.

6. "Resources Allocation to Optimize Mining Pollution Control," EPA-600/2-76-112--a model developed to predict pollution loads and direct efforts for the most cost effective pollution abatement.

7. "Erosion and Sediment Control," EPA-625/3-76-006--a two-volume manual for planning and design of sediment control structures.

8. "Assessment of Environmental Aspects of Uranium Mining and Milling," EPA-600/7-76-036--a preliminary assessment of the environmental impact associated with production of domestic uranium ores.

Feasibility studies or interim reports were published for the projects involving underground mine daylighting, debris basin effectiveness for sediment control, surface and underground mine sealing in the Tioga River Watershed, coal mine haul road sediment control, and the use of fly ash for surface mine reclamation in Hillman State Park. In addition to these, two draft reports are being reviewed for the major efforts dealing with the assessment of coal transport and the assessment of head-of-hollow fill and mountaintop removal mining.

CONCLUSIONS

The work of EPA and other agencies has led to more effective pollution control technology for mining and to more environmentally sound and efficient mining methods. Recent publications of ETB, concerning sediment pond construction and control structures for sediment control, have had a major positive impact on the industrial community. The cooperative project of ETB and the Bureau of Mines regarding coal haul roads, is not only a major effort toward controlling the adverse effects of one of industry's most troublesome pollution sources, but also a demonstration that the interests of two federal agencies can be combined in a single effort too large for either to undertake alone. Other coordinated contributions from various federal agencies will be part of the total mining pollution control picture in supplying assessment data, biological recovery studies, seed sources, revegetation techniques, groundwater information, etc.

Health effects, water treatment schemes, sludge disposal, revegetation, mine closure, groundwater control, and formation of viable regulations are all areas for continued research. The basic mechanisms in the formation and control of mining pollution are well known. Active research and demonstration projects are paving the way toward greater understanding and more advanced and economical mining and pollution control methods. The small questions raised in present research and development efforts are the research needs and full-scale demonstration projects of the future. By looking to what we have found, and what we are finding today, we can project what will be necessary tomorrow.

DEVELOPMENT PROGRESS IN COAL CLEANING FOR DESULFURIZATION

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INTRODUCTION

Sulfur oxide air pollution emissions from coal combustion exceeded 20.5 million tons in 1974. With the increasing use of coal as an energy source, improved methods are needed for the control of this pollutant. Major strategies for the control of SO_2 emissions include the use of coal cleaning, the combustion of coal in chemically active fluidized beds, the removal of pollutants by flue gas scrubbing and the generation of clean synthetic fuels. An economically attractive control strategy is coal cleaning. The EPA Office of Energy, Minerals and Industry supports a comprehensive program for the development and demonstration of coal cleaning for SO_2 emission control. Major activities and significant results of this program, which is directed by the Industrial Environmental Research Laboratory, Research Triangle Park (IERL-RTP), are described in this paper.

TECHNICAL STATUS

Coal Cleanability

The sulfur content of coal ranges from less than 1 to more than 7 percent. Sulfur appears in coal in three forms: mineral sulfur in the form of pyrite (FeS_2), organically bound sulfur and trace quantities of "sulfate" sulfur. Sulfate sulfur occurs in coal as a result of the attack of oxygen on the mineral pyrite. It is soluble in water and can be removed in wet coal preparation plants. Organic sulfur occurs as part of the organic coal structure and cannot be removed by physical coal preparation techniques. Pyrite occurs in coal seams in sizes ranging from small discrete particles to large lumps. It can be found intimately dispersed in the coal substance, in bands, in layers or in large pieces.

Physical preparation or cleaning techniques are capable of removing varying fractions of the coal pyritic sulfur as determined by the properties of each coal. Chemical processes are capable of removing over 95 percent of the pyritic sulfur and up to about 70 percent of the organic sulfur.

Laboratory float-sink studies have been performed on over 455 U. S. coals to determine their physical cleanability. (1) The samples tested were from mines in the six major coal producing regions of the U. S., the mines which provide more than 70 percent of the coal used in U. S. utility boilers.

The results of these float-sink tests indicate that in general pyrite removal increased with reduced particle size and lowered specific gravity of separation. This fact is extremely important. It implies that to enhance pyritic sulfur removal more of the coal must be crushed and processed at finer particle sizes than historically practiced in coal preparation. A second important fact determined by these studies is that the final sulfur levels to which coals can be cleaned vary from coal region to coal region and from one coal bed to another within the same region (coal cleanability also varies to a significant extent from location to location within the same mine).

Sulfur removal by chemical methods is dependent upon coal properties and process conditions--time, pressure, temperature, and chemical reagents. A number of investigators have studied these relationships (2) (3). In some instances the availability of information is limited because it is considered to be proprietary. Process costs will probably limit the amount of sulfur which can be removed to about 95 percent of the pyritic sulfur and 40 percent of the organic sulfur.

Figure 1 presents parametric relationships between the degree of cleaning (pyritic and organic sulfur reduction), the sulfur level of the cleaned coal and the percentage of utility coals which can be cleaned to a specified sulfur content.

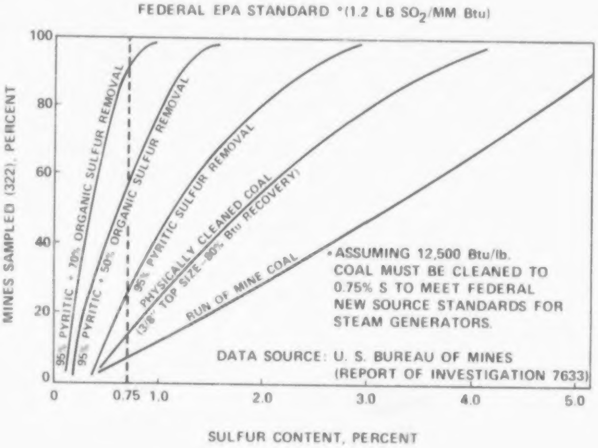

Figure 1. Potential levels of desulfurization for U.S. utility coals.

Coal Cleaning Costs

The costs of physical and chemical coal cleaning for sulfur removal are to a large extent undefined. Physical cleaning has traditionally been used to remove ash and mining residues from coals. There is virtually no data correlating costs and sulfur removal in commercial coal cleaning equipment. However, substantial data exists on the costs of cleaning for ash removal. Using this data one can deduce the costs of sulfur removal from correlations between ash and sulfur removal in commercial equipment. While these correlations are few and tenuous they do provide estimates which indicate that in some cases physical coal cleaning will be a more cost effective emission control technique than flue gas desulfurization (FGD). However, physical cleaning is not a panacea since it cannot remove organic sulfur from coal or in some cases sufficient pyritic sulfur, to meet a specified emission level.

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(1) Superior numbers refer to similarly numbered references at the end of this paper.

Chemical coal cleaning is capable of removing nearly all the pyritic sulfur and a substantial fraction of the organic sulfur. However, chemical cleaning is more costly than physical cleaning. Costs for its use may range from the costs of FGD to the costs of producing synthetic fuels from coal. Further, because of their early state of development, the estimated costs for chemical coal cleaning are less certain than those for physical cleaning.

A major goal of the IERL-RTP coal cleaning program is to develop data on the performance and cost of equipment and processes for removing sulfur from coal.

Status of Coal Cleaning Technology

Physical coal preparation processes for steam coal are oriented toward the removal of ash and mining residue. The physical removal of pyritic sulfur from steam coal has not been commercially used as a method of SO_2 emission control. The physical removal of pyrite will require crushing to fine particle sizes prior to separation. Separation at these fine sizes while not impossible represents a shift to a mix of equipment and operating conditions which is different from those traditionally used for steam coal preparation. Dewatering and drying of a large percentage of fine coal may be required for many of the new plants.

The variability of sulfur forms within a coal bed or mine presents a special problem which will require the development of improved technology if coal cleaning is to be used for SO_2 emission control. Mining and blending methods are needed to attenuate the sulfur variations in the plant feed, and process instrumentation is needed for measurement and control of the product sulfur level.

Chemical coal cleaning is in the early stages of development and it is estimated that a commercial plant could not be put into operation for at least 5 to 10 years. At least 23 chemical coal cleaning processes have been identified by EPA. However, many of these processes are either conceptual only, are not presently active, have never been tested on coal, or do not result in coal-like products. Only seven or eight processes appear to merit serious consideration at this time. Factors which determine the potential use of these processes include: the amounts and types of sulfur removal, process costs, state-of-development, and residue disposal problems. An EPA report describing the development status of each of these chemical coal cleaning processes is to be published in the near future.

Options for Using Coal Cleaning

Physical coal cleaning can be used on a limited number of U.S. coals to meet Federal New Source Performance Standards (NSPS) for steam generators. Moreover a large number of coals can be physically cleaned and used (1) to meet less stringent state SO_2 emission standards or (2) in conjunction with flue gas desulfurization (FGD) to lower emission control costs.

Only 14 percent of the 455 U.S. coals tested by the Bureau of Mines are capable of meeting NSPS without cleaning$^{(1)}$. Crushed to a top size of 1-1/2 in. and cleaned to a Btu recovery of 90 percent (10 percent of the heat from the mined coal would be lost), a total of 24 percent of these coals could meet NSPS. The percentage of coal which will be cleaned to NSPS levels could be increased by either a reduction in the coal particle size or a reduction in the Btu recovery value of the cleaned product. In the latter case a middling coal fraction could probably be used in a boiler with FGD.

A much larger percentage of coals can be cleaned to meet standards which in some locations are as high as 5 to 6 lb $SO_2/10^6$ Btu. For example, 36 percent of the 455 U.S. coal samples tested by the Bureau of Mines would be able to meet a standard of 2.0 lb $SO_2/10^6$ Btu when reduced to 1-1/2 in. top size and cleaned to a Btu recovery level of 90 percent. For these same cleaning conditions over 65 percent of the samples would be able to meet emission standards of 4.0 lb $SO_2/10^6$ Btu.

A note of caution is needed. The percentages of coals which can be cleaned to specific sulfur levels relate only to those mines tested. It would be erroneous to conclude that these same values apply to the percentage of U.S. coal reserves which can be cleaned to specific sulfur levels. An estimation of the cleanability of the U.S. coal reserves will soon be available from studies now in progress.

The use of physical coal cleaning in combination with flue gas desulfurization (FGD) represents an approach where the advantages of each technique can be used to minimize emission control costs while permitting the most effective use of U.S. coal resources. A recent study on the use of a combination of physical coal cleaning and flue gas desulfurization shows significant economic advantages to this combined pollution control method.(4) In 36 case studies in areas where local regulations for SO_2 emissions vary from 1.2 to 1.6 lb $SO_2/10^6$ Btu, the cost of using a combination of conventional coal cleaning and flue gas desulfurization was 2 to 55 percent lower than flue gas desulfurization alone for new plants and 10 to 60 percent lower for existing plants. The arithmetic average for the cases cited showed costs which were about 30 percent lower for new plants and 40 percent lower for existing plants.

PROGRAM DISCUSSION

The IERL-RTP coal cleaning program includes a wide range of activities from research on the characteristics of coal to the demonstration of commercial coal preparation processes. The program is divided into subprograms for: (1) the assessment of pollution from coal cleaning, coal transportation and coal storage, (2) the development of physical and chemical processes for removing contaminants from coal and (3) the development of pollution control technology for coal preparation processes. In addition to contract R&D directed by IERL-RTP, cooperative projects are conducted with (1) the U.S. Bureau of Mines (USBM), (2) the U.S. Geological Survey (USGS), and (3) the Energy Research and Development Administration (ERDA), and the Electric Power Research Institute (EPRI). The following paragraphs discuss the status of projects under each of the three coal cleaning subprograms.

Environmental Assessment

The overall objectives of the environmental assessment activities have been to characterize coal contaminants and identify the fate of these contaminants during coal processing and coal use. Initial studies have focused on sulfur and potentially hazardous accessory elements (minor and trace elements) contained in coal. Future studies will also evaluate potentially hazardous organics which may be leached from coal and coal residues.

Trace Elements in Coal. EPA has supported research at the Illinois Geological Survey (IGS) to evaluate the occurrence and distribution of trace elements in coal. This work has been supported by the Synthetic Fuel and Coal Cleaning programs at IERL-RTP. Analyses have been completed on 172 whole coal samples. Of these, 114 samples were from the Illinois Basin, the remaining samples were from other coal-producing areas of the U.S. Analyses have been made to determine the occurrence and distribution of trace elements as a function of the vertical segment of the coal seam (bench) and the specific gravity of the crushed samples. Further, an index of organic affinity was calculated from the specific gravity fractions of these coals. This index permits one to estimate the manner in which various elements will be distributed during coal washing.

Conclusions from these studies which provide insight into potential environmental problems associated with the preparation and use of coals include:

(1) Elemental concentrations tend to be highest in coals from the Appalachians, lowest in coals of the Western United States, and intermediate in coals from the Illinois Basin.

(2) Elements that have the largest ranges in concentrations are those that are found in distinct mineral phases in coal; elements with narrow ranges are found in organic combination in coal.

(3) On the average only four elements (boron, chlorine, selenium and arsenic) are present in coals at concentrations significantly greater than the average concentrations in the earth's crust.

(4) Benches of a single coal seam often exhibit wide variations in elemental concentrations. High concentrations are most commonly observed at the top and/or bottom of the coal seam.

(5) Major quantities of elements with high inorganic affinities may be removed from coals by specific gravity cleaning techniques - disposal of these residue materials in turn may pose a significant environmental problem.

Work at IGS will be continued to extend the mineralogical and chemical characterization of coals, especially as related to the distribution of elements and minerals during specific gravity separation.

Characterization of Coal Preparation Wastes. EPA and ERDA are sponsoring research at the Los Alamos Scientific Laboratory (LASL) to: (1) characterize the trace elements and mineralogy of coal preparation wastes, (2) evaluate the leaching of trace elements under environmental conditions (laboratory simulated), and (3) evaluate technology applicable to the control of environmental pollution from trace elements in coal refuse.

Initial studies have concentrated on coal wastes from four different preparation plants in the Illinois Basin. Trace elements and minerals in these wastes were identified. Associations were established between the trace elements and major minerals to evaluate the potential for release of trace elements under environmental weathering conditions. Laboratory leaching studies were conducted to simulate environmental weathering of these wastes. Variables included surface area (size), time, temperature, pH, access to air and oxidizing bacteria.

Leaching increased with decreasing pH, increased availability of air, increased surface area and increased leaching time. Experiments using oxidizing bacteria are not complete. Highly leachable elements of environmental concern included: Be, Al, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Cd and Tl.

Continuing studies will focus on similar evaluations of coal preparation wastes from Appalachian and Western coals. Also, various methods for controlling the leaching of these elements or the clean-up of leachant will be investigated.

Environmental Assessment Project. A three year project to assess the environmental impacts of coal preparation, coal transportation and coal storage is being conducted for IERL-RTP by the Battelle Columbus Laboratories. Major project activities include:

(1) The development of a technology overview containing a description of all current coal cleaning processes and their associated pollution control problems.

(2) The development and performance of an environmental test program to obtain improved data on pollutants from commercial coal cleaning plants.

(3) The performance of trade-off studies to evaluate the relative cost effectiveness of coal cleaning as compared to other SO_2 emission control strategies (primarily FGD).

(4) The performance of studies to determine the relative environmental impacts of coal cleaning and FGD.

Progress during the first year of this project has included the completion of a technology overview study and the development of a plan for environmental testing at commercial coal preparation plants in the U.S. The second year of the program will include environmental testing at four to five preparation plants and the initiation of trade-off studies on alternative SO_2 emission control strategies.

Combustion of Hydrothermally Treated Coals. Laboratory experiments were run to evaluate sulfur and trace element emissions which result from the combustion of coals treated by the Battelle Hydrothermal Process. These experiments were conducted in a 1 lb/hr laboratory combustor at the Battelle Columbus Laboratories. Tests were conducted using raw coal, coal leached with sodium hydroxide, and coal leached with a mixture of sodium hydroxide and calcium hydroxide. Coals from the Martinka and Westland coal mines were evaluated. Generally, the sulfur content of the treated coals was reduced below 0.6 lb $S/10^6$ Btu on a moisture and ash free basis. Corresponding values in the untreated coals ranged from approximately 1.5 to 2.5 lb $S/10^6$ Btu. During combustion from 25 to 75 percent of the fuel sulfur was retained in the combustor ash and fly ash. Generally, ash sulfur retention in the mixed leachant coals was superior to that in the coals treated with NaOH. During combustion experiments with untreated coals, sulfur retention in the ash ranged from 3 to 30 percent. The emission of trace elements from combustion of the treated coals was substantially reduced when compared to corresponding combustion products from the raw coals.

Combustion experiments in commercial sized boilers will be required to confirm the results of these laboratory experiments.

Geologic Variability of Coal Contaminant. The USGS is studying the variability of contaminants within coal seams under an interagency agreement with EPA. The objectives of this project are to:

(1) Determine the geologic factors controlling the lateral variation, vertical variation, crystal form and size of pyrite in coal.

(2) Determine the geologic factors controlling mineral and elemental variations in coal, especially as related to the possible separation of the organic and inorganic fractions of coal during physical cleaning.

(3) Evaluate various methods for correlating coal cleanability with its petrologic characteristics.

(4) Develop methodology for determining the cleanability of coal in the U.S. reserves.

Initial studies in satisfying these objectives will focus on the Upper Freeport seam near Homer City, PA. The USGS studies will complement other EPA studies at the PENELEC Homer City coal cleaning plant which are directed to the development of mining schemes which will aid in the removal of coal contaminants during preparation.

The USGS project began in October 1976. Core hole and mine face samples are now being evaluated. Several mines have been inspected and field trips have been made to determine the geological history of the area surrounding the Homer City power complex.

Coal Cleaning Technology Development

Major projects under the coal cleaning technology development subprogram include: (1) a detailed assessment of existing equipment and processes which can be used for coal desulfurization; (2) the development of new desulfurization processes and (3) the demonstration of physical coal cleaning as an effective method for SO_2 emission control for utility boilers.

Technology Assessment. A major three year project to assess technology for the physical and chemical desulfurization of coal was begun in January 1977. This project is being conducted by Versar, Inc., with the assistance of the Joy Manufacturing Co., Denver Equipment Division. The principal project activity will be to develop data on the performance of commercial coal cleaning equipment in separating fine coal and pyrite. The capital and operating costs associated with pyrite removal will also be identified. Similar cost and performance evaluations will be made on equipment for dewatering and drying fine coal. Other project activities will include: an evaluation of chemical coal cleaning processes; an evaluation of coal preparation requirements for synthetic fuel conversion processes; an evaluation of pollution control technology used for coal cleaning; and the conduct of engineering trade-off studies to establish the performance and costs of coal preparation plants designed for improved pyrite removal and Btu recovery.

Progress to date has included the collection of existing data on coal cleaning for pyrite removal and the construction of a mobile laboratory to facilitate equipment testing at commercial coal preparation plants.

Homer City Coal Cleaning Demonstration. The Pennsylvania Electric Company (PENELEC) is constructing a 1200 tph coal preparation plant at their Homer City power complex. When completed the plant will provide physically cleaned coal to two existing 600 MW units and one new 650 MW unit. The cleaning plant is to be used in place of scrubbers to meet Pennsylvania and Federal SO_2 emission regulations.

EPA, PENELEC, EPRI and ERDA are cooperatively supporting a demonstration program at the Homer City complex. EPA plans to provide approximately two-thirds of the funds in support of an estimated $4 million test and evaluation program. The objectives of the demonstration program are to:

(1) Determine the variability of sulfur and other pollutants in coal fed to the cleaning plant.

(2) Determine the performance of equipment used for the separation of coal and pyrite.

(3) Determine the capability of plant process controls to maintain the coal product streams within sulfur, ash and Btu specifications.

(4) Characterize pollutant streams emitted from the preparation and power plants.

(5) Determine if a need exists for the development of improved pollution control technology.

(6) Evaluate the effects of using clean coal on the performance of the boilers and electrostatic precipitators at the power plant.

(7) Evaluate the effectiveness of planned residue disposal techniques.

(8) Determine the fate of potentially hazardous minor and trace pollutants contained in the coal used at the preparation and power plants.

(9) Determine capital and operating costs of the preparation and power plants; i.e., the costs of using physical coal cleaning to meet SO_2 emission regulations.

(10) Evaluate other equipment or coal cleaning circuits as needed to demonstrate the viability of the Homer City plant for cleaning coal to meet SO_2 emission regulations.

The preparation plant is scheduled to begin start-up tests late this spring. Pilot plant tests are underway at the U.S. Bureau of Mines test facility in Bruceton, PA. Several baseline environmental tests have been completed and the development of detailed test plans has been started. Cooperative studies with the USGS to evaluate the variability of sulfur in the Homer City reserves are in progress.

Technology Development (USBM). EPA is supporting a number of coal cleaning R&D projects through an interagency agreement with the Department of the Interior. Coal cleaning technology development activities include research performed by the USBM Coal Preparation and Analysis Group at Bruceton, PA. and contract work directed by them. Major active projects during the past year included research or demonstration on the following:

(1) Studies on the cleanability of selected U.S. coals (USBM project).

(2) Surface phenomena in the dewatering of coal (Syracuse University research grant).

(3) Control of black water in coal preparation plant recycle and discharge (Penn State University).

(4) High gradient magnetic separation (General Electric Co. and Massachusetts Institute of Technology).

(5) Absorption-desorption reactions in desulfurization of coal by pyrite flotation (University of Utah).

(6) Computer simulation of coal preparation plants (University of Pittsburgh).

(7) Engineering and economic analysis of coal preparation for SO_2 emission control (Hoffman-Munter Corp.).

(8) Design of a coal preparation test facility (Birtley Engineering).

(9) Evaluation of stabilization agents for coal preparation plant sludges (Dravo Corp.).

A summary of these USBM coal cleaning R&D activities is given in a separate paper included in the proceedings of this conference.

TRW Chemical Coal Cleaning Process. In previous years EPA supported bench and laboratory scale development work on coal desulfurization by aqueous ferric sulfate leaching. This process developed by TRW is capable of removing from 90 to 95 percent of the pyritic sulfur in a varietv of U.S. coals. Construction of 1/3-ton per hour reactor test unit (RTU) capable of pilot scale testing has been completed at Capistrano, California.

The plant dedication took place on April 22, 1977. The safety review and system check-outs were completed in early May and cold flow tests were completed in mid-May. Hot flow tests with water are scheduled for completion in early June. Pulverized coal will be circulated through the RTU in June to verify system functions. Initial test runs are planned for August. An initial nine month test program is planned to verify major process variables.

Thermochemical Desulfurization Process. Institute of Gas Technology (IGT) under EPA contract has been developing a thermalchemical process for coal desulfurization. This process is capable of removing both organic and pyritic sulfur from coal. Products of the process are a low sulfur coal char and a low Btu gas. The principal achievement to date has been the validation of the process concept. Operating conditions have been determined with both laboratory and bench scale equipment. Tests showing satisfactory desulfurization of four coals representing abundant, high sulfur, eastern coal reserves have been completed. In each case the treated product could be burned without exceeding present Federal EPA SO_x emission standards for coal fired steam generators.

The achievement of satisfactory desulfurization was the result of a discovery that mild, oxidative pretreatment of the coal rendered the organic sulfur more amenable to removal; until this discovery sulfur removal had been unsatisfactory. It now appears that the IGT system may be a viable alternative for making a low sulfur, solid, fossil fuel from high sulfur U.S. coals which cannot be adequately desulfurized by physical cleaning.

Microwave Desulfurization. Laboratory experiments by the General Electric Company have demonstrated the technical feasibility of coal desulfurization by microwave energy. Both pyritic and organic sulfur appear to be removed. Pyrite is preferentially excited by the microwave energy producing volatile or water soluble sulfur compounds which may be easily removed from the coal. Coal-NaOH mixtures exposed to microwave energy show a reduction of organic sulfur after washing. The coal organic structure and NaOH absorb little microwave energy at the treatment frequency (8.3 GH_z). However, it is postulated that sufficient energy is absorbed by water in the coal to cause reactions between NaOH and the coal organic sulfur.

Laboratory experiments are continuing to evaluate the mechanisms of coal desulfurization by microwave energy and identify those process variables which will increase sulfur removal.

Pollution Control Technology Development

The subprogram to develop coal cleaning pollution control technology is in its assessment phase. Projects to develop improved pollution control technology will be initiated as the need for improved pollution control methods are identified.

CONCLUSIONS

Physical and chemical coal cleaning can be used to meet a variety of State and Federal SO_2 emission regulations, singly or in combination with flue gas desulfurization. IERL-RTP projects now in progress will:

(1) Provide needed data on the performance and costs of coal preparation for coal desulfurization.

(2) Demonstrate the economic and technical feasibility of using coal cleaning as an SO_2 control strategy.

(3) Characterize the cleanability of U.S. coals by physical and chemical methods.

(4) Develop methodology to determine the cleanability of U.S. coal reserves.

(5) Identify pollution emission and waste disposal problems for coal cleaning, coal transportation and coal storage which require the development of improved pollution control technology.

(6) Continue the development of promising physical and chemical coal cleaning techniques.

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CONVERSION FACTORS

The following conversion factors may be used to convert from the English units used in this paper to metric units.

1 inch = 2.54 cm
1 tph = .907 metric tph

$$1 \frac{\text{lb}}{10^6} \text{ Btu} = 2.326 \frac{\text{Kg}}{10^3} \text{ Joule}$$

U.S. ENVIRONMENTAL PROTECTION AGENCY SPONSORED RESEARCH AT U.S. BUREAU OF MINES

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INTRODUCTION

Increased national attention is presently being paid to coal and its preparation to meet energy demands consistent with environmental legislation. The Bureau of Mines has increased its efforts in developing improved technology in preparing coal and new methods for removing sulfur and fugitive elements. EPA has provided both funds and moral support for the Bureau's research program at a time when both were badly needed. This paper will describe in brief form, the substance of each project sponsored by the EPA, as well as to present the more recent developments in each area of funding.

IN-HOUSE RESEARCH

Characteristics and Removal of Pyritic Sulfur From Selected U.S. Coals

In 1965, the National Air Pollution Control Administration (later EPA) funded a continuing study by the Bureau of Mines to determine the forms of sulfur in the major sources of utility steam coals, and the washabilities of these coals. The purpose of this investigation was to determine the effects of crushing and gravimetric separation on the liberation and removal of pyritic sulfur and other impurities for coals collected from the principal utility producing coalbeds of the United States. Information generated from this study is necessary to assess the impact physical coal cleaning might have on the level of sulfur oxide emissions from stationary combustion sources.

The latest publication reporting the results of this study is Report of Investigations 8118 entitled "Sulfur Reduction Potential of U.S. Coals." This publication covers work performed from 1965 to mid-1974 and presents the results of washability studies of 455 raw coal channel samples collected from six coal producing regions of the U.S.

Figure 1 shows that only 14 percent of raw coal samples as mined could meet the new source SO_2 emission standard of 1.2 pounds SO_2/MM Btu. Twenty-four percent of the samples would meet the standard at a 90 percent Btu recovery when crushed to 1-1/2 inches top size, while 32 percent would meet the standard at a Btu recovery of 50 percent when crushed to 14-mesh top size. This figure has been frequently misinterpreted so an explanation seems warranted. Actually, 40 percent or 183 of the 455 samples tested can be upgraded to meet sulfur dioxide emission standards with a total Btu recovery of 86 percent. Some of the 183 samples were quite refractory and gave recoveries ranging from 5 to 20 percent. On the other hand, 122 samples could be beneficiated with Btu recoveries of 90 percent or more.

Since RI 8118 was published, 27 samples from the Western Region States and about 100 samples from the States of Pennsylvania, Ohio, West Virginia, Maryland and Kentucky have been processed. Because of the increasing interest in lignites, 6 samples of Texas lignite 2 samples of Arkansas lignite have been collected and are now being analyzed.

In addition, a report compiling proximate and ultimate analyses, Btu/lb., Free Swelling Index, and Hardgrove Grindability Index for each of the samples presented in RI 8118 is being prepared and should be completed by the end of this year.

Coal Preparation Process Development Facility

In order to alleviate many of the past problems of introducing new technology to the industry, a central coal preparation process development facility has been designed and specifications prepared for construction. When completed and operational the test facility will provide engineering data on a variety of coals which can be scaled up to full-size commercial coal preparation plant operation. Moreover, the expense of evaluating processes that prove to be of limited value to the industry will be greatly reduced.

The pilot plant section of the proposed facility will have a nominal capacity of 10 to 25 tons per hour of raw coal depending on the flowscheme used; process flexibility was a prime design requisite of this pilot plant. The facility will also contain an equipment area smaller in scale than the pilot plant to initiate work on research projects before they are taken into the pilot plant section for scale-up.

The architects delivered site preparation bid documents to the Bureau in May of this year. Construction of the facility (raw coal handling, equipment and process development, and the pilot plant) could begin before the end of calendar year 1977.

CONTRACT RESEARCH

Commercial Installation of Coal-Pyrite Flotation Process

The Bureau of Mines is cooperating with Barnes and Tucker to demonstrate the commercial feasibility of the Bureau developed Coal-Pyrite Flotation Process. The process involves the depression of coal with a hydrophilic colloidal substance while the coal-pyrite is floated with a sulfhydryl collector. The Coal-Pyrite Flotation Process has been tested and proved effective in a Bureau pilot

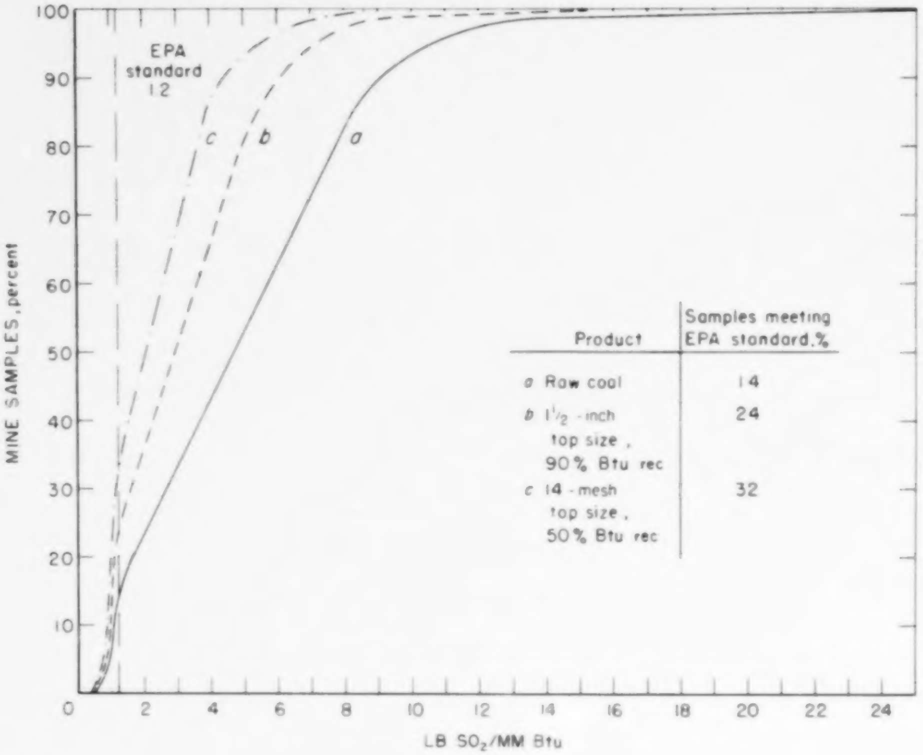

Figure 1. Percent of 455 U.S. coal samples meeting the EPA New Source Performance Standard of 1.2 pounds SO_2/MM Btu.

plant study. If the process works successfully in the Barnes and Tucker Plant, it will mean the recovery of an additional 8 tons per hour of fine-size coal which is now being discarded as waste because of its high sulfur content.

This plant was designed to prepare coal for the metallurgical market by incorporating heavy media cyclones, hydrocyclones, and standard flotation cells. A second flotation cell was also included to permit an additional 10-12 ton-per-hour yield from a classifying cyclone underflow if seam sulfur content was low.

However, consistently high-sulfur-content coals were encountered in the mining process making it impossible to utilize the secondary flotation cell product in producing a coal sufficiently low in sulfur to satisfy the metallurgical market.

Heyl and Patterson, Inc. (designer and builder of the original plant) has completed the engineering required and has begun purchasing the equipment necessary to make the modifications to the plant. Shown in Figure 2 is a schematic of the changes incorporated into the circuitry; construction work should be finished by August 1977. Subsequently, flotation tests will be run for about 1 year. The test results will then be evaluated and a report written for publication and information dissemination.

Adsorption-Desorption Reactions in the Desulfurization of Coal by a Pyrite Flotation Technique

Research is being conducted at the University of Utah to investigate the depressant and collector adsorption reactions which occur during coal desulfurization by the Bureau's Coal-Pyrite Flotation Process. The project has the expressed purpose of determining if a separation technique can be developed whereby primary pyrite flotation is followed by a second-stage coal flotation, the purpose being to produce a final clean coal product that is in thickened form ready for dewatering. A second purpose is to investigate the effect of residual reagent that might appear in plant recycle water. Specific objectives of this research program include:

1. Identify and characterize the hydrophilic polymeric coal depressants.
2. Determine the important operating variables which control the adsorption-desorption reactions and relate these results to the flotation response of the mineral constituents.
3. Establish procedures, if necessary to allow for subsequent coal flotation and plant water recycle without deleterious effects due to residual reagent concentrations.

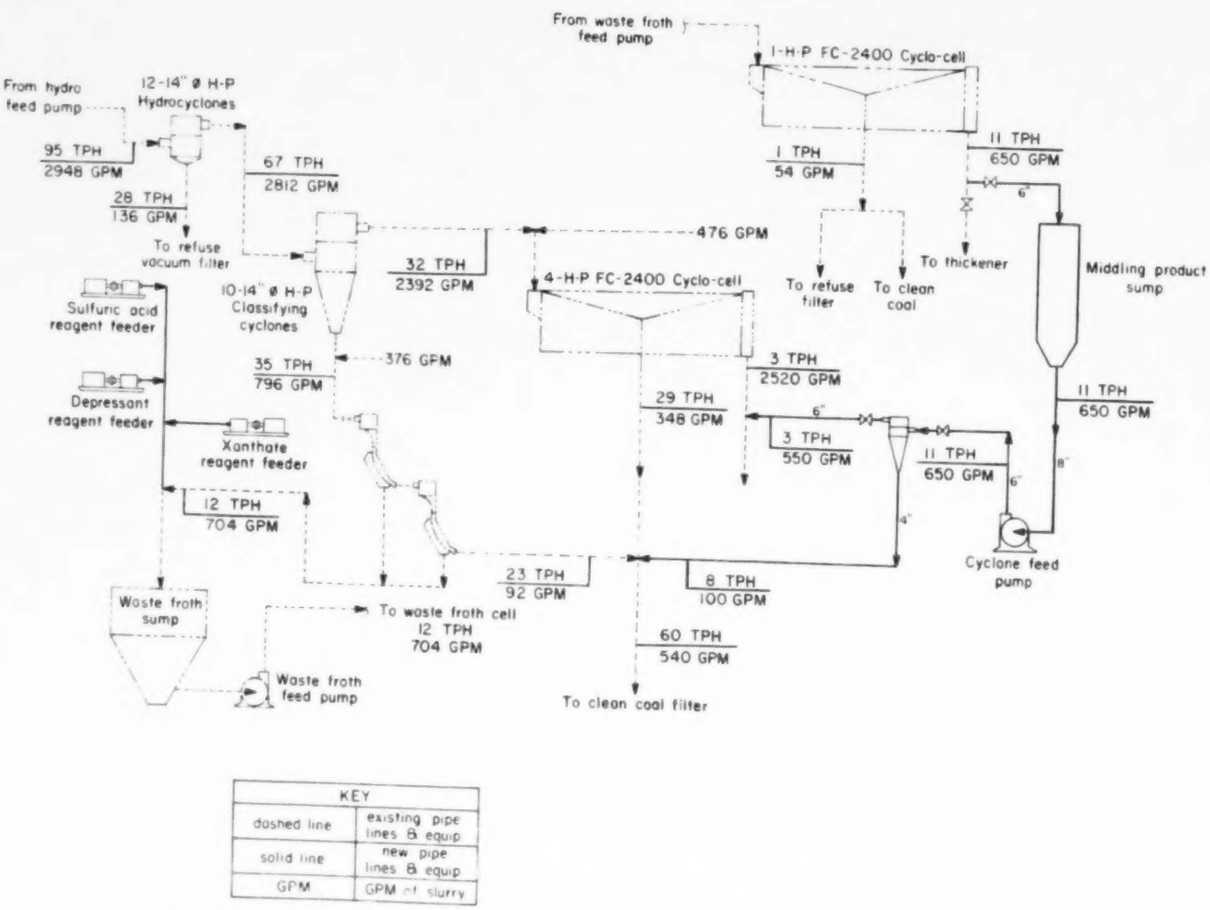
From waste froth feed pump
1-H-P FC-2400 Cyclo-cell
From hydro feed pump
12-14" ø H-P Hydrocyclones
95 TPH
2948 GPM
67 TPH
2812 GPM
28 TPH
136 GPM
To refuse vacuum filter
1 TPH
54 GPM
11 TPH
650 GPM
6"
-476 GPM
32 TPH
2392 GPM
4-H-P FC-2400 Cyclo-cell
To refuse filter
To clean coal
To thickener
Middling product sump
Sulfuric acid reagent feeder
10-14" ø H-P Classifying cyclones
35 TPH
796 GPM
376 GPM
3 TPH
2520 GPM
Depressant reagent feeder
Xanthate reagent feeder
29 TPH
348 GPM
6"
3 TPH
550 GPM
11 TPH
650 GPM
11 TPH
650 GPM
6"
8"
4"
12 TPH
704 GPM
23 TPH
92 GPM
8 TPH
100 GPM
Cyclone feed pump
Waste froth sump
To waste froth cell
12 TPH
704 GPM
60 TPH
540 GPM
Waste froth feed pump
To clean coal filter
KEY
dashed line
existing pipe lines & equip
solid line
new pipe lines & equip
GPM
GPM of slurry

Figure 2. Flow scheme modifications for coal pyrite flotation process.

In research work done to date on this project, dextrin, amylose, and Aero Depressant 633 were found to have a similar depressant effect on coal flotation. Addition of any of these reagents in excess of .02 pounds per ton of coal depresses at least 80 percent of the coal. Desorption of the depressants from the coal surface was found to be difficult and the adsorption reaction appears to be irreversible. However, the depressed coal can be reactivated and floated by the addition of neutral molecular oil. Also, as shown in Figure 3, even large additions of coal depressant do not interfere with pyrite flotation.

The coal-pyrite materials used in this study were found to contain significant amounts of marcasite. The material's flotation response to xanthate collector is inferior to that of ore pyrite. This is probably due to its porous, clay-filled surface structure which tends to remain hydrophilic. The flotation response of coal-pyrite can be improved by using higher collector concentrations, by performing the flotation at lower pH values, and by using the longer hydrocarbon chain xanthates.

From the knowledge gained in the depressant and collector studies, bench-scale coal flotation experiments are now being conducted in an effort to find optimum conditions to depress coal particles and float pyrite. During these flotation tests the residual depressant concentration will be measured and water recycle experiments will be done to determine the effect on subsequent coal flotation.

High-Gradient Magnetic Separation for Removal of Inorganic Sulfur From Coal

General Electric Company is attempting to establish the technical feasibility of removing a substantial fraction of the inorganic sulfur from dry coal powders at commercially significant processing rates. Reduction of sulfur by HGMS could permit the direct combustion of large coal reserves east of the Mississippi River, which have a high percentage of pyritic sulfur but are low in organic sulfur.

Initial testing was done utilizing aqueous slurries with modest results in removing pyritic sulfur, as well as ash. Recently, dry separation test runs were made. The results show:

(a) there is evidence of some magnetic separation,

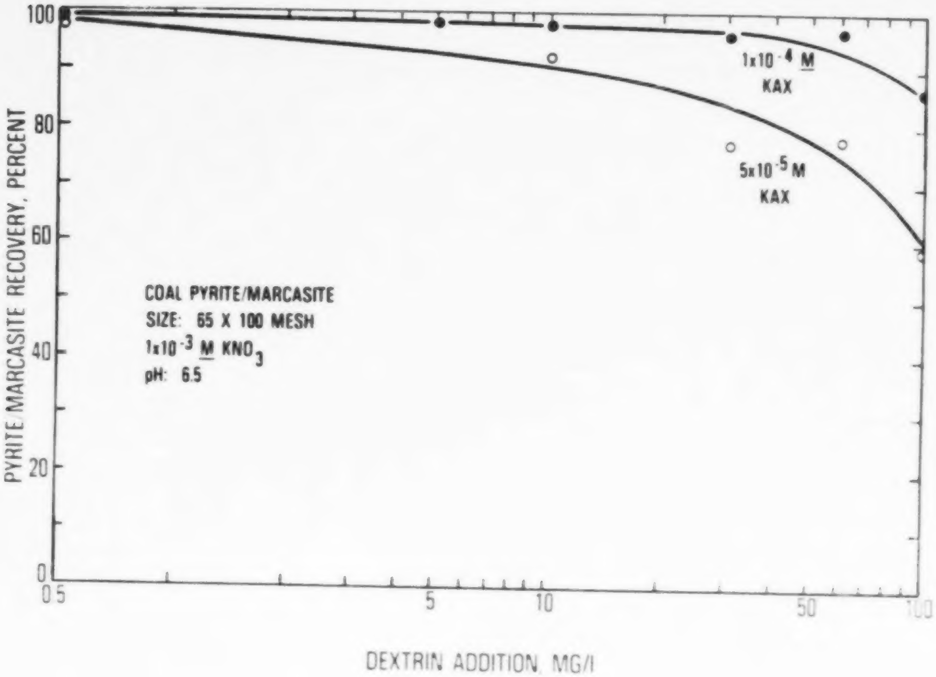

Figure 3. Effect of dextrin addition on coal pyrite flotation with potassium amyl xanthate (KAX) as collector.

(b) the amount of sulfur and ash removal is much smaller than that in the case of water slurries, and

(c) no significant trend in sulfur or ash removal emerges from changes in applied magnetic field or in flow velocity, or with changing from an expanded metal to a steel wool matrix.

The poor separations appear to be both a result of agglomeration of particles and a result of particles adhering to the filter fibers. Both of these problems are likely induced by electrostatic charging of the particles and subsequent agglomeration.

Because of the problem of poor performance of the separator with dry coal, a two-month funded extension has been requested on this contract to further pursue the origins of the poor performance with the hope of understanding and improving the dry separations.

Surface Phenomena in the Dewatering of Coal

Rotary vacuum filters are relatively economical and practical devices for dewatering froth flotation concentrates and flocculated slurries, but the product usually retains over 20 percent moisture. As a result, thermal drying, a comparatively expensive process, is often required to reduce the moisture content of the filter concentrate to an acceptable level. An investigation to improve mechanical methods for dewatering fine coal so that the need for thermal drying will be minimal, is being carried out under a grant with Syracuse University.

In this investigation, experiments are being conducted to characterize the dewatering of fine-size coal, to estimate the effect of an electric field on the dewatering process, to determine the influence that slurry pH has on dewatering, and to assess the influence of selected chemical additives on moisture retained in filter cakes. Further, reagent adsorption tests are being carried out to develop relationships between the performance of a reagent as a dewatering aid and its adsorption on the coal surface.

During the first year, a test system was devised, constructed and tested. The system appears to provide the critical parameters necessary for the evaluation of reagents as a dewatering aid in filtering fine coal. Recently, the accumulated test data on the effects of various cationic, anionic, and nonionic surfactants have been used to formulate a model for surfactant behavior in a cake of fine-size coal and its effect on the dewatering of coal.

Control of Black Water in Coal Preparation Plant Recycle and Discharge

Treatment of black waters from coal preparation plants is complicated by their heterogeneous nature and by the lack of information on the behavior of relatively simple systems. This water consists of mixtures of fine coal, clay minerals, quartz, calcite, pyrite and other mineral particles dispersed in water. Effective treatment of the effluents must be carried out regardless of whether the water is to be reused or discharged.

Under a grant with the Pennsylvania State University, a laboratory investigation of the flocculation process is being carried out in the treatment of black water from coal preparation plants. In this investigation, a quantitative evaluation is being made of the interrelation of flocculation rate, settling rate, and sludge volume to establish a technique for producing as dense a sludge as possible in a thickener operating at the highest possible rate. Further, the results of studies on the flocculation of heterogeneous systems will be used to develop mathematical models to simulate the flocculation of particles in practical systems.

Studies of the characteristics of actual black water are nearing completion. The mineralogical composition and particle size distribution have been determined on samples collected from preparation plants operating in most of the major coal producing regions and coal seams in the United States. The results show that the chemical and physical characteristics of samples collected from the eastern and interior provinces are essentially the same. Although verifying data are not yet available, samples collected from western operations appear to be somewhat different.

Tests are currently proceeding on the specific interactions of polymeric flocculants with the surfaces of coals and coal-related minerals.

Computer Simulation of Coal Preparation Plants

To assist in the prediction of full-scale coal preparation plant operation, a computer simulation program is being developed under contract with the University of Pittsburgh. The first phase of this work included the partial development of an overall computer program that would simulate the performance of a coal preparation plant for a specified coal feed. Included within the program is performance data for each of the commonly used coal washing devices. Specifically, the program simulates the operations of the following units:

1. Concentrating table.
2. Dense-medium cyclone.
3. Dense-medium vessel.
4. Hydrocyclone.
5. Dyna-whirlpool vessel.
6. Baum jig.
7. Froth flotation cell.

The program also includes mathematical modeling of the rotary breaker, other crushers, screens (both wet and dry), centrifugal dewatering equipment, thermal dryers, and thickeners. The program is structured so that it can be used in either of the following two ways:

1. To predict the performance of a given plant configuration for a specified set of operating conditions.
2. To determine the operating conditions resulting in a specified ash and pyritic sulfur reduction for a given plant configuration.

Engineering/Economic Analysis of Coal Preparation With SO_2 Cleanup Processes for Keeping Higher Sulfur Coals in the Energy Market

In a study recently completed for the Bureau of Mines by the Hoffman-Muntner Corporation, the economic potential of coal preparation in combination with stack gas scrubbing was evaluated. Generally speaking, of the various methods for reducing the sulfur content of coals, the physical removal of pyritic sulfur is the lowest cost and most widely applied technology. However, a number of those coals currently being mined and utilized cannot, by physical upgrading alone, meet the new-source sulfur emission standard of 1.2 pounds of SO_2 per million Btu. The concept of physical coal cleaning combined with flue gas desulfurization is not new. For some time, there have been discussions, speculations, and some preliminary assessments addressing the possible benefits of physical coal desulfurization followed by flue gas desulfurization.

The Hoffman-Muntner study is an in-depth analytical assessment of a number of theoretical case studies. In these studies, actual coal use areas, coal source areas, and the most probable coalbed source are defined. An economic evaluation is then made of the cost of a new utility plant exclusively removing SO_2 by stack gas scrubbing down to the new source emission standard. This is followed by a similar evaluation of the combined use of physical coal cleaning plus stack gas scrubbing to attain the same sulfur emission level. The study concluded that, in general, the combination of coal preparation and stack gas scrubbing was less expensive than scrubbing alone.

Analysis of Chemical Coal Cleaning Process

Many coals, even after physical coal cleaning have sulfur levels too high to meet Federal air quality standards when burned due to the organic sulfur content which cannot be removed physically. The Bechtel Corporation recently completed an analysis of six chemical coal cleaning processes in a study for the Bureau of Mines. Chemical coal cleaning offers the advantage of, at least theoretically, removing all pyritic sulfur, some of the ash, and up to 40 percent of the organic sulfur.

The six processes studied were:

1. The Hazen Process.
2. The KVB Process.
3. The TRW - Meyers Process.

4. **The Battelle - Hydrothermal Process.**
5. **The Ledgemont Oxygen Leaching Process.**
6. **The ERDA Oxidative Desulfurization Process.**

Process flow charts were drawn for each process and analyzed in terms of cost and sulfur removal performance. While none of the processes is economically competitive with physical cleaning, the Bechtel report concludes that the six processes represent the starting point for engineering improvement and for generating new concepts.

Evaluation of the Effect of Coal Cleaning on Trace Elements

There is an acute awareness that trace elements in coal might contribute substantial quantities of potentially hazardous materials to the environment. Much of the 650 million tons of coal mined annually in the United States goes to power plants where it is burned. Thus, a coal containing concentrations of only one part per million could emit hundreds of tons of a potentially hazardous substance into the environment each year.

Certain trace elements may selectively concentrate in particular specific gravity fractions of the raw coal and, if so, may be readily removed by conventional coal washing processes prior to combustion.

The Bureau of Mines recently completed a washability study showing the trace element contents of various specific gravity fractions for 10 coal samples collected from various coal producing regions of the United States. Reliable analytical methods were developed to determine cadmium, chromium, copper, fluorine, mercury, manganese, nickel, and lead in the whole coals and the various specific gravity fractions of the coals.

As shown in Table 1, most of the trace elements of interest concentrated in the heavier specific gravity fractions of the coal, indicating that they are associated with mineral matter, and removal of this material would result in significant trace element reductions ranging up to 88 percent.

In a related, but greatly expanded effort, the Bureau, through EPA, has just funded a three-phase program with Bituminous Coal Research. The objectives of this project are:

	Cumulative analyses								
		Parts per million							
Product	Yield, percent	Cd	Cr	Cu	F	Hg	Mn	Ni	Pb
	Northern Appalachian Region								
Float 1.60	88	0.08	18	8	39	0.12	7	10	2.9
Composite raw coal	100	.11	21	12	58	.23	12	13	6.2
Reduction, percent		27	14	33	33	48	42	23	53
	Southern Appalachian Region								
Float 1.60	77	0.12	10	21	26	0.06	68	13	8
Composite raw coal	100	.12	25	31	110	.09	300	19	15
Reduction, percent		0	60	32	77	33	77	32	47
	Eastern Midwest Region								
Float 1.60	91	0.03	11	5	48	0.07	13	9.6	3.7
Composite raw coal	100	.34	12	6.3	54	.09	47	9.8	5.6
Reduction, percent		88	8	21	11	22	72	2	34
	Western Region								
Float 1.60	91	0.07	3.6	6.7	32	0.04	16	4.0	5.1
Composite raw coal	100	.10	3.7	7.6	40	.06	45	4.1	7.1
Reduction, percent		30	3	12	20	33	64	2	28

TABLE 1.

SUMMARY OF COMPOSITE PRODUCT ANALYSES BY REGION FOR COALS CRUSHED TO 14 MESH TOP SIZE AND CLEANED AT 1.60 SPECIFIC GRAVITY SHOWING THE TRACE ELEMENT REDUCTION ATTAINABLE

1. To complete a comprehensive, state-of-the-art study on the fate of fugitive elements in coal mining, preparation, transportation, and utilization;

2. To determine the association and concentration of elements in the ash minerals, sulfide minerals and clean coal.

3. To develop and describe analytical methods, including new methods for determining fugitive elements in the PPM and PPB range.

SUMMARY

This brief report of EPA sponsored research at the U.S. Bureau of Mines shows the wide spectrum of interest in physical, as well as chemical coal preparation.

FOREST SERVICE MINING RECLAMATION RESEARCH

Grant Davis
Surface Environment and Mining Program
Forest Service
U.S. Department of Agriculture
Billings, Montana

INTRODUCTION

Successful reclamation depends on many factors: effective planning, proper mining techniques which maintain hydrologic integrity and form stable spoils suitable for plant growth, timely revegetation with adapted species, and transportation systems which cause little environmental damage.

Knowledge of the physical and chemical characteristics of the soils and rock strata that form the overburden above the coal is essential for planning mining and reclamation. If strata with undesirable characteristics can be identified before mining, they can be placed where least harm will result. On the other hand, the materials more favorable to plant growth can be placed on the surface. Condition of the ground water must also be determined so that its flow and quality can be reestablished after mining. The best way to obtain data on overburden and ground water hydrology is through core drilling. Although much drilling has been done to obtain information on coal deposits, the technology for drilling and analyzing overburden is not well developed. Little is known about the physical changes that take place after the rock strata are mined and exposed to weathering.

In addition to the hydrologic impacts of mining a specific area, the cumulative effects of several mines on a large watershed are difficult to predict. In the West where water resources are so scarce, it would be desirable to create ponds on mined areas. To date there is no information on how to construct ponds which provide suitable habitat for wildlife or livestock use.

Revegetation of mined areas is necessary to put the land back into productive use, prevent erosion, and restore aesthetic values. Successful establishment of plants depends upon selection of species adaptable to the area, seedbed preparation, and careful planting on favorable spoil. In many cases spoils are lacking in nutrients and need to be improved for better plant growth. Some non-mine waste products may be suitable as spoil amendments. Use of such waste materials as sewage, processed garbage, bark and other fiber by-products as spoil amendments will also help solve serious waste disposal problems. This is a comparatively new field of research, and recent emphasis on recycling has produced many by-products which can be tested on spoils. However, it is important to guard against the inherent danger of releasing toxic substances into the environment.

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Transportation systems associated with mining can cause considerable environmental damage during active operations. Roads are especially subject to erosion from water and wind. Dust is a nuisance, a safety hazard, and an air pollutant, but little quantifiable data is available to assess damage or to establish corrective measures.

During the mining and reclamation process, a considerable amount of engineering, physical and biological data are collected. Computer hardware and software must be developed in order to integrate environmental constraints with mining operations.

It does little good to develop reclamation technology unless the information is readily available to potential users. Computer systems are generally inadequate for storing and retrieving data and information, especially in the West.

TECHNICAL DISCUSSION

Revegetation technology must be developed regionally because of the different climates and species involved. In the relatively humid Appalachia and Midwest regions many species can survive and grow on spoils; so there are opportunities to select those which offer some economic return. After a thorough literature search on the subject, former researchers and practitioners were contacted for their opinions. This preliminary work was useful in developing a rough outline of chapters for a technical handbook on revegetation in the East.

Initial field work consisted of remeasuring some of the older Forest Service experimental plantings in Missouri, Kansas, Oklahoma, Ohio, Illinois, Indiana and western Kentucky. Soil samples to help relate growth to spoil type were also collected. As the survey of West Virginia, Pennsylvania, Alabama and Tennessee is completed, all the data will be compiled and analyzed for the handbook. In addition to the spoil characteristics, information on elements which are toxic to plants is being compiled. An important addition to the data on adaptation of species to mine spoils will be the Soil Conservation Service report based on 22 years of field plantings.

Non-mine waste products and other mulches are being evaluated as spoil amendments in Alabama, Tennessee, Kentucky and Pennsylvania. Materials tested include leaves, wood chips, bark, a soil stabilizer, composted trash and sewage, and harbor silt. Data on runoff, spoil moisture, sediment, vegetation and precipitation are being collected. The largest study of non-mine waste is on the Palzo strip mine in southern Illinois. Sewage sludge has been applied at rates of 150 and 285 dry tons per acre on over 30 acres. Twenty-four experimental plots have been established to test 17 species of trees and shrubs and seven herbaceous species. Water quality at four-foot depths was monitored during application. In addition to the field tests, measurements of nutrient and heavy metal content of plants grown on sludge-amended spoils in the greenhouse were also completed.

In the Southwest, germination and planting techniques are being investigated for five species. Field treatments designed to establish vegetation on coal spoils involve contour furrowing at 8 and 20-foot spacings and incorporation of six tons per acre of wood chips or straw. Eight species of native shrubs and grasses grown in containers were planted on the test plots. As part of this study, three-element type sensors were developed to measure spoil moisture, salinity and temperature.

Experimental revegetation plots have been established on coal spoils in Montana, Wyoming and Utah. A study was installed to determine appropriate rates and frequency of fertilizer application for establishing various species of grasses, forbs and shrubs. Direct seeding is being compared to planting containerized seedlings to find which is more effective for plant establishment. The effects of four different types of spoil on plant growth are being tested in the field, as well as using bioassay techniques in the greenhouse. Various treatments of topsoil, bark-wood fiber compost and hay mulch have been applied on plots in the Alton, Utah, coal field. A university has been contracted to study the microbiology of untreated and amended spoils. In an attempt to provide plant materials more suitable for hostile spoils of the semiarid West, two universities were contracted to develop superior shrubs and grasses.

Spent oil shales present a more difficult challenge for revegetation than coal mine spoils. A greenhouse bioassay study was completed using five non-mine waste amendments on leached and unleached TOSCO spent shale. Sewage sludge had greater beneficial effects on plant growth than wood fiber, straw, sugar beet pulp, or cow manure. Sewage sludge apparently ties up the sodium salts in spent shale. Field plots were established in the oil shale areas of Colorado and Utah. Different depths of topsoil were applied to spent shale, and test species of grasses and shrubs were grown under irrigated and nonirrigated conditions. There was little difference in growth on the topsoil treated shale, but irrigation was beneficial on raw shale. Soil covering over a depth of one foot gave better plant growth than shallower soil coverings. Other studies are designed to compare fall seeding with spring-planted containerized stock and to assess the significance of snow accumulation behind standard snow fencing. One study showed that plants grew better on shale covered with topsoil or subsoil than when mulched with rock or straw.

A study of ponds on surface mines in the Northern Great Plains was initiated by a rather extensive literature research on the subject. Over 400 articles have been collected using six retrieval systems. Besides gathering the information in one place, the literature review helped to define what characteristics make a pond attractive to wildlife and what water quality parameters are important for adequate growth of aquatic food plants and invertebrates. With this background, the ponds for lentic studies and streams for lotic studies were selected. In the East, a hydrologic study to assess the effects of coal mining on three watersheds in each of about 130 counties in Appalachia was started in April, 1977.

Of the transportation systems related to mining, the road networks cause the most environmental damage. Much of sediment and dust generated by mining activities comes from roads. Mathematical models to predict runoff and sediment yields from roads are being adapted to the surface mine situation. Subroutines for snowmelt runoff and chemical water quality impacts are also being developed. Collection of data on runoff and sediment yield from field plots in order to calibrate the models is underway. A detailed study plan on fugitive dust has been prepared prior to a field study to begin this summer.

A watershed on the Thunder Basin National Grassland in Wyoming has been selected to demonstrate efficient core drilling design and core analysis techniques. Some of the holes will be cased to serve as wells to determine quality and flow characteristics of ground water. Guidelines for drilling, sampling and core analysis are being prepared which outline procedures to be followed by land managers in obtaining data and information necessary for leasing, mining and reclamation.

Data are being collected from a series of studies covering mass stability, physical transformation of overburden materials by weathering, and erodibility of spoils. A preliminary model for the stratification of materials within spoil piles has been assembled in Bozeman, Montana, and is operational. Environmental constraints are being programmed into the system in order to determine their effects on mine productivity.

A computer system to store and retrieve bibliographic references on mining and reclamation has been established at the University of Arizona. Before the contract was let to the University, a survey of potential users was conducted to determine need for a technical information service and to assure that duplication of current or planned services would not occur. Documents related to reclamation of surface mined lands have been accumulated, and a mailing list of users has been compiled. A computer-produced literature citation bulletin, called SEAMALERT, is being published periodically and circulated via the mailing list. Agencies using this service are being contacted in an attempt to secure funding for SEAMALERT on a continuing basis.

PROGRAM DISCUSSION

Revegetation technology is generally well developed in the East and Midwest, and the results are accepted and put into practice to a large extent. However, the large number of small mines operating over extensive areas makes it difficult to get the latest research results to the many practitioners on a timely basis. Another difficulty in dealing with small operators is a lack of trained reclamation staff that can readily understand and apply new technology. Many Forest Service and Soil Conservation Service personnel work with mine operators, but the task is too large for individual consultation to be used efficiently. A handbook on revegetation will be an extremely valuable tool in distributing revegetation knowledge on a large scale. It will also be useful as a basic text in training sessions and workshops on revegetation.

The situation is entirely different in the West. Since the mines in the West are large operations and usually have trained reclamation personnel, it is easier to get new technology to the users quickly. As in the East, the companies are eager to obtain and apply new methods for revegetation. This is especially true because the state-of-the-art is not as far along as in the East. Forest Service scientists have worked with company practitioners, and many research results have been put into use even before they have been published. However, there will be less opportunity to work hand-in-hand with the companies in the future because of the rapid expansion of mining activity. By the time the revegetation handbooks are published, they will probably be the most efficient way to get new technology to the new practitioners.

Interest in using non-mine wastes for mulches and spoil amendments is increasing, especially in the East where waste products are generated closer to the areas being mined and logistic problems are thus more easily solved. Disposal of waste is also a more serious problem in the East, and the waste producers are more willing to participate in the research and delivery problems. Although sewage sludge has a good potential as a spoil amendment, there is a reluctance to utilize this waste product because of aesthetics and a resistance of local residents and companies to use their land as a "dumping ground" for other people's wastes. There is also a fear of introducing toxic elements into areas where the livestock industry and wildlife resources are so important to the economy.

Many of the larger companies are beginning to use computers and mini-computers to handle their engineering data related to mine development and production. They have shown much interest in the models being developed to incorporate environmental constraints into their computer programs. They also see the opportunity to utilize these programs to help store and manipulate data in the preparation of Environmental Impact Statements.

Demonstration of core drilling design and procedures to obtain information on overburden and ground water would not have been possible without funding from the Environmental Protection Agency. Mining companies are generally interested in the project, and personnel from four large companies are participating in the study.

SEAMALERT has been well recieved by the users that have been contacted. A true test of its value will be their willingness to fund the project on a permanent basis.

CONCLUSIONS

Although most of the reclamation research tasks are not yet completed, some areas needing additional work have been identified. The problems of mined area stability are proving to be difficult to solve in the West as well as in Appalachia. Fugitive dust is not only difficult to measure, but research on control technology has not even been considered for the most part. Development of reclamation models is in its infancy, and adding subroutines of the various environmental components will take a major effort before the models will be used to any great extent.

The interest in using revegetation technology as soon as research results are available in the West is very encouraging. It is also heartening to realize that reclamation technology is being developed and will be ready before much land is disturbed in the western coal fields. It is good to be ahead of the game for once.

PROTECTION OF SOIL AND WATER RESOURCES ON LAND DISTURBED BY MINING

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INTRODUCTION

Strip mining is commonly used to extract coal -- one of our many natural resources. However, in this highly populated world, the principles of wise conservation and utilization of natural resources require that the technology used to extract the coal results in as little damage as possible to our soil and water resources associated with these deposits. Our soil and water resources are the ultimate source of food and fiber, so they need to be preserved in the mining process.

The Agricultural Research Service (ARS) of the U.S. Department of Agriculture and the State Agricultural Experiment Stations are the only government agencies whose prime mission is to conduct research related to agriculture. In keeping with its mission, ARS has for the past decade been involved in the development of technology to restore agricultural productivity to land disturbed by mining. Because sustained agricultural production depends on the preservation and efficient utilization of soil and water resources, the ARS mission to restore agricultural productivity coincides with that of the U.S. Environmental Protection Agency (EPA) to maintain environmental quality. Thus, since 1975, ARS reclamation research has been partially supported by a grant from EPA. In this paper, a review is presented of ARS reclamation research, particularly those objectives being investigated under the EPA contract.

ARS reclamation research is being conducted at nine locations. Scientists at two major locations, Morgantown, WV, and Mandan, ND, conduct research primarily to characterize the nature of spoils and overburden, to determine plant growth requirements, and to develop agronomic and engineering practices that will permit economic production of agriculturally important plant species on mined land. A similar approach is also used on a smaller scale at Beltsville, MD, Blacksburg, VA, and Cheyenne, WY. At Ft. Collins, CO, and University Park, PA, work is directed toward hydrological and engineering studies needed for developing technology to control water quality and movement through and out of mine spoils. Research at Peoria, IL, and Ithaca, NY, while limited in scope, is aimed primarily at investigating quality of vegetation produced on mined land, with particular emphasis on potential health hazards. ARS is also conducting hydrological studies on mined land at Coshocton, OH, financially supported, in part, by the U.S. Bureau of Mines.

TECHNICAL DISCUSSION

Essentially all land disturbed by mining will eventually have some type of vegetative cover, regardless of its post-mining use. Since vegetative cover affects soil water relations and the extent of erosion, soil and water resources on mined land can be protected by controlling the type and amount of vegetation present. In addition, agricultural benefit can frequently be derived from revegetated land. In keeping with this line of thought, much of the ARS reclamation research is designed to restore and enhance the potential for plant growth on disturbed land.

The initial major research effort by ARS was identifying those physical and chemical properties of mine spoils that restrict the potential for plant growth (3, 5, 6, 15, 21, 22). This required numerous samplings and laboratory analyses of mine spoils. Concomitantly, methodology for sampling and analyses had to be determined to provide data that could be best interpreted in terms of potential plant growth. Fortunately, most procedures normally used to develop agronomic recommendations for unmined land were applicable to mine spoils.

Eastern U.S. Mine Spoils

Factors restricting plant growth on mined land are often greatly different for humid and semiarid regions of the United States. In the humid east, problems resulting from actual or potential acidity of spoils predominate (3, 6). In highly acid materials, the solubility of such elements as iron, aluminum, manganese, and copper is frequently high enough to be toxic to plants. On the other hand, magnesium, calcium, and phosphorus availability to plants is sometimes inadequate to support growth. Many eastern spoils contain a high percentage of sand, which tends to make them droughty. Also many of the mining methods result in steep outer slopes, which are erosive and difficult to stabilize.

The acidity problems encountered in the east can be corrected by applying limestone, especially dolomitic limestone (Table 1), which also corrects the calcium and magnesium deficiencies (11). Rock phosphate contains calcium as well as phosphorus, and can be used successfully when soil pH is below 4.5 (1). Nitrogen deficiencies are corrected either by fertilizing with nitrogen, producing legumes, or by adding nitrogen-containing organic residues like manure or sewage sludge (3, 6). However, sewage sludge frequently contains several toxic heavy metals; hence rate of application must be controlled to avoid excessive uptake of heavy metals by plants.

Proper selection of plant species is a very important part of reclamation. Research has shown that with appropriate treatment, almost all plant species commonly produced in the East can be grown on mine spoils (3, 6, 13). However, where steep slopes remain after mining, generally only perennial grasses will provide the erosion protection needed. Although commercial forestry is a possible post-mining land use, research results presently available indicate that perennial grasses and legumes

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TABLE 1.

RESPONSE OF WEEPING LOVEGRASS AND CROWN VETCH TO LIME AND FERTILIZER AT WHITE OAK MOUNTAIN, WEST VIRGINIA (3)

Treatments[a]	Dry Matter Yield			pH
	1970	1971	1972	1971
	lb/acre			
No lime, no phosphorus	1,390	2,854	2,950[b]	3.52
3,750 lb/a phosphate rock	4,381	5,157	4,198	3.80
7,500 lb/a phosphate rock	4,162	4,510	3,742	4.15
750 lb/a superphosphate	3,700	4,510	4,198	3.45
1,500 lb/a superphosphate	3,629	4,630	3,526	3.08
16,000 lb/a dolomite	822	-	3,382	5.65
16,000 lb/a dolomite plus 7,500 lb/a phosphate rock	956	-	2,135	5.86
16,000 lb/a dolomite plus 7,500 lb/a phosphate rock	822	-	3,886	5.66
16,000 lb/a dolomite plus 750 lb/a superphosphate	4,064	3,742	3,718	5.67
16,000 lb/a dolomite plus 1,500 lb/a superphosphate	3,358	2,423	6,141	5.90

[a] 125 lb/a of nitrogen and 100 lb/a of potassium applied to the experimental area as uniform amendments.

[b] Weeping lovegrass stand diminishing and crownvetch became the dominant plant species.

should initially be seeded on mined land to achieve soil stabilization. Later the land may be converted to forestry uses. Directly seeding or transplanting forestry species into spoils on steep slopes usually results in excessive erosion and runoff.

By proper selection of grasses and legumes, a profitable grazing enterprise can be established on reclaimed land. Thus economic benefit can be derived from such land while at the same time providing environmental protection. If spoils are highly acid (pH 4.5 or less), the best adapted grass species are weeping-lovegrass, bermudagrass, tall fescue, switchgrass, crown-vetch, and birdsfoot trefoil. For higher pH material, species like orchardgrass, bromegrass, ryegrass, alfalfa, and several of the clovers (6) can be used (Table 2). On sites with moderate slopes, it is feasible to produce annual crops like corn, small grains, oil crops, and vegetable crops. Recent advancements in the development of "no-till" systems of production are making it more feasible to produce some of these crops on slopes greater than 10%.

Seedling establishment in spoils is frequently difficult because the lack of active organic matter results in crusting, rapid drying, and poor physical conditions. These problems can be temporarily solved by applying various types of organic mulches, such as straw, wood chips, paper pulp, and others. Also, a high degree of success in grass establishment can be obtained by seeding grass directly into the stubble of a small grain crop (12). Once a grass stand has been established, organic matter begins to accumulate in the surface layers of the spoil. At one site in West Virginia, within 2 years after grass establishment, organic matter content of the upper 8-inch depth increased from 0.2 to 2.0%, and pH increased from 3.8 to 5.9 in 4 years (3).

Problems related to the low organic matter content of spoils can often be partially or completely overcome by returning soil material to graded spoils. Most states now have laws making this a required practice, if soil material is available. However, frequently only a few inches are available to be returned.

In Appalachia much of the mining is done on the contour, often resulting in outer slopes of 60% or more. However, even slopes this steep can be stabilized and made productive by proper treatment (Table 3). A very promising technique is to create miniature contour terraces (about 8 inches wide) every few feet down the slope. After properly liming and fertilizing these terraces and spreading seed, excellent stands of weeping lovegrass and crown vetch have been established, which provide both adequate protection against runoff and erosion and also vegetation useful for grazing by livestock and wildlife (2). Wheel-tracking (using the cleats of a bulldozer to form miniature contour

TABLE 2. ANNUAL DRY FORAGE YIELDS OF GRASSES GROWN ON THE SPOIL FERTILITY PLOTS AT WHITE OAK MOUNTAIN, WEST VIRGINIA (3)

Spoil[a] Amendments	Dry Forage Yields															
	Bromegrass				Orchardgrass				Ky 31 Tall Fescue				Timothy			
	1971	1972	1973	1974	1971	1972	1973	1974	1971	1972	1973	1974	1971	1972	1973	1974
	t/a															
Superphosphate	3.4	1.9	2.8	3.2	2.7	1.3	2.8	3.3	3.6	2.7	3.3	3.4	-	2.8	3.8	4.2
Superphosphate plus potassium	1.8	1.6	2.5	3.2	2.5	1.5	3.3	2.8	2.9	2.5	3.2	3.3	-	2.2	3.8	3.8
Superphosphate plus limestone	3.0	1.8	2.8	3.4	3.0	1.5	2.3	3.0	3.7	2.6	3.2	3.7	-	2.2	3.3	4.1
Phosphate rock plus potassium	2.7	2.0	3.1	3.9	3.1	1.7	3.2	3.7	3.9	2.7	4.0	3.9	-	2.6	4.2	4.7
Phosphate rock	2.7	1.7	2.8	4.5	2.9	1.6	3.7	3.7	3.8	2.8	4.0	4.6	-	2.6	4.7	4.9

[a] 50 lb/a of nitrogen applied before seeding, and 200 lb/a topdressed in the springs of 1972-73-74. Other treatments were: superphosphate = 320 lb/a P_2O_5; rock phosphate = 2 t/a; potassium = 200 lb/a; and limestone = 2 t/a.

TABLE 3.

YIELD OF WEEPING LOVEGRASS AND BIRDSFOOT TREFOIL MIXTURE AS AFFECTED BY PHOSPHATE TREATMENTS ON OUTER SLOPES AT WHITE OAK MOUNTAIN, WEST VIRGINIA (3)

Phosphorus treatment		Method of Legume	Dry Matter Yield	
Material	Rate	Establishment	1971	1972
			lb/acre	
Rock phosphate,	2 t/a	Seeded	3,445	5,333
		Transplanted	3,398	7,964
Rock phosphate,	3 t/a	Seeded	5,677	7,156
		Transplanted	2,311	6,428
Rock phosphate,	4 t/a	Seeded	3,446	7,020
		Transplanted	4,518	5,477
Superphosphate,	320 lb/a	Seeded	3,094	7,020
		Transplanted	5,853	7,020

[a] Uniform applications of amendments included 50 lb/a of nitrogen, 150 lb/a phosphorus, 2 t/a of dolomite, and 1 lb/a molybdenum.

furrows by driving up and down the slope) is commonly practiced by mining operators.

Western U.S. Mine Spoils

In western United States, on mined land as well as on unmined land, lack of plant-available water ultimately limits plant growth. Any reclamation practice or alteration of spoil property that increases water infiltration, reduces evaporation, or increases potential plant growth generally improves the efficiency of water conservation and use (17).

Properties of soils and overburden of major concern include salinity levels, exchangeable sodium content, nutrient deficiences (especially nitrogen and phosphorus), toxicities (magnesium, boron, molybdenum), compaction, and steep slopes. To obtain valid data on spoil and soil properties, it is important that methods used to collect and analyze samples are reliable, accurate, and capable of being interpreted. Acceptable procedures are presently being published (16, 24).

Many spoils, especially in North Dakota and New Mexico, are high in exchangeable sodium content, resulting in deteriorated soil structure, reduced infiltration, and greater crusting (23). Research results have shown that in about 3 years after treatment with gypsum, up to about 50% of the exchangeable sodium can be displaced and leached out, resulting in some improvement in water relations (15). Exchangeable sodium can be almost completely removed in just a few days by treating spoils with calcium chloride, but this treatment is very expensive not only because of the cost of the chemical, but also because the soluble salts that are formed by this reaction must be leached out with several acre feet of irrigation water before plant growth is possible (7).

Salinity (total dissolved salts) increases the osmotic potential of soil water, thus reducing the availability of water for plant growth. Salinity levels commonly found in western mine spoils are usually classified as moderate (EC x 10^3 = 8 mmhos/cm). However, when higher salinity levels are encountered, very few plant species can be used. The effect of salinity on many species often varies with stage of growth (20). Certain salts -- such as those of boron, magnesium, or molybdenum -- may be present at levels that are toxic to some species.

Phosphorus is almost universally deficient in western spoils (4, 17). However, spoils are generally near neutral or alkaline (pH 6.5 to 9.0) and contain free calcium carbonate, so fixation of added phosphate fertilizers is somewhat reversible, and deficiencies are readily corrected with phosphatic fertilizers. Spoils may contain appreciable exchangeable ammonium, which is readily nitrified upon exposure to the atmosphere (14). However, biologically active organic nitrogen is absent and must be restored by building up the level of soil organic matter.

Appreciable quantities of soil material are often available for spreading over spoils after smoothing. Research in North Dakota (Table 4) has shown that about 30 inches of suitable soil material must be returned to highly sodic spoils (SAR> 15) to restore them to their full productivity potential for crops commonly grown (17). Presumably with better quality spoils, less soil material would be required. However, as little as 2 inches of soil material, placed on sodic spoils, produced yields of crested wheatgrass and native grasses (Table 5) equal to 50 to 70% of those obtained with 30 inches or more of soil material. Returning topsoil helps alleviate the poor physical conditions caused by high sodium content, as well as problems related to nutrient deficiencies, toxicities, and soil water relationships.

Topography of pre-mined western coal fields is generally much smoother than that in the eastern U.S., so slopes remaining after mining are generally less steep. However, in western mine spoils slopes often exceed 9%, with slope length of several hundred yards. Hydrological data indicated that the potential for runoff and erosion on long slopes of 9% or greater is severe (9, 10). Also preliminary data indicated that both wind and water erodibility of freshly spread soil material may be several-fold greater than that of unmined soil (Table 6). The K factor, predicted from soil properties and used in the Universal Loss Equation, usually underestimates erodibility of topsoil over mined land (8). Consequently, soil and water conservation on mined land is best achieved by reducing slopes to less than 9%, and preferably to less than 5%, to the extent possible.

The lower precipitation received in the western U.S. makes the establishment of a vegetative cover more difficult than in eastern U.S. Because vegetative cover is often more sparse in the West, protection of soil and water resources is more feasible by keeping slopes to a minimum. Data indicate that seedling establishment can be improved by use of various types of mulches, standing stubble, or a thin layer of soil material, gravel, or even oxidized coal -- if not too high in soluble salts (17, 25). Adding a few inches of water during critical periods in the year of plant establishment can affect the kinds of species established and and their density (18, 19). This quantity of water is often available as pit water. Even though pit water is usually high in soluble salts, it appears that it can be used beneficially on all but the most arid sites.

Most mine spoils in the western U.S. are returned to perennial grasslands for eventual use by grazing livestock and wildlife. Considerable research is in progress to determine soil and environmental requirements for the various species and to accelerate natural succession of native species. In more favorable precipitation areas, annual small grains (wheat) are produced on reclaimed mined lands. Also it is desirable to establish woody plantings in the drainageways to provide protection to livestock and wildlife during adverse weather and for browse.

PROGRAM DISCUSSION

As a result of research conducted by ARS, technology is being developed that protects the soil and

TABLE 4.

YIELD OF FIRST HARVEST OF
SEVERAL CROPS AS AFFECTED
BY THICKNESS OF SUBSOIL
AND TOPSOIL SPREAD OVER
SODIC (SAR = 26)
MINE SPOILS

Topsoil Thickness inches	Subsoil thickness, inches 4	12	20	28	36	44	52	60
		A. Spring wheat yields, bu/a						
0	11.9	15.8	17.8	19.2	18.8	18.6	19.6	18.6
8	23.9	28.5	29.1	28.9	29.5	29.0	30.2	28.6
24	29.2	30.0	30.5	30.5	28.8	29.9	30.9	31.7
Mixed [1/]	15.7	20.0	21.9	22.4	23.2	22.0	22.5	21.6
		B. Alfalfa (first cut), t/a						
0	0.048	0.20	0.36	0.43	0.37	0.31	0.37	0.39
8	0.32	0.28	0.56	0.51	0.60	0.57	0.52	0.54
24	0.41	0.42	0.44	0.47	0.41	0.59	0.54	0.48
Mixed [1/]	0.057	0.17	0.36	0.43	0.55	0.47	0.51	0.54
		C. Crested wheatgrass, t/a						
0	0.87	1.12	1.29	1.36	1.50	1.24	1.55	1.43
8	1.26	1.43	1.45	1.65	1.48	1.40	1.55	1.41
24	1.24	1.31	1.41	1.45	1.37	1.46	1.26	1.38
Mixed [1/]	0.71	1.12	1.50	1.45	1.57	1.33	1.47	1.50
		D. "Native" grasses [2/], t/a						
0	0.008	0.068	0.053	0.081	0.14	0.12	0.15	0.13
8	0.21	0.27	0.39	0.46	0.47	0.39	0.35	0.29
24	0.15	0.060	0.22	0.19	0.16	0.11	0.12	0.14
Mixed [1/]	0.00	0.003	0.038	0.073	0.046	0.038	0.15	0.16

[1/] Topsoil and subsoil mixed in 1:3 ratio.

[2/] Blue grama and sideoats grama.

TABLE 5. DRY WEIGHT YIELD OF A NATIVE GRASS MIXTURE SEEDED IN 1970 ON SPOILS WITH AND WITHOUT 2 INCHES OF TOPSOIL (17)

Year	Without Topsoil	With Topsoil
	------ t/a	-------
1973	0.21	0.69
1974	0.06	0.77
1975	0.11	0.74
1976	0.12	0.56

TABLE 6. SIMULATED RUNOFF AND SOIL LOSS FROM UNDISTURBED RANGELAND AND MINE SPOILS (10)

Land Use [1/]	Runoff	Soil Loss
	inches	t/a
Rangeland	0.04	0.2
Spoil	2.0	7.2
Spoil covered with topsoil (25 cm)	1.6	32.6

[1/] 9 to 10% slope with 4 inches water added with a Purdue Rainulator in 4 hours to initially wet soil material.

water resources of mined areas and also provides an economic return to the landowner. It is apparent that the best way to achieve these dual objectives is to establish good productive vegetative cover. Once established, this vegetation not only restricts surface water movement and erosion, but possibly more important, it also dries the soil, enabling more of the precipitation received to infiltrate into the soil at the point of impact. Also, by drying the soil, the quantity of water and the quantity of dissolved solids passing below the root zone to the watertable is reduced. This, in turn, aids in controlling groundwater pollution from mined areas. Revegetation adds organic matter and plant nutrients to the upper surfaces of mined land. Rapid establishment and efficient production of vegetation is one of the best defenses possible to guard against soil and water degradation on land disturbed by mining.

Although this research is clearly defining the role of vegetation and slopes in controlling environmental quality of reclaimed land, much additional information is needed. Research has not been conducted long enough to fully evaluate long-term effects of reclamation practices. Questions regarding various aspects of long-term stability -- stability of the vegetation, of the landscape, and of the ability for sustained production -- are largely unresolved. On many spoils, particularly those high in sodium, mass instability is evident. Instability is expressed by settling over prolonged time periods, differential rates of subsidence, development of piping type of erosion, and slippage. Additional research is needed in soil mechanics and engineering to develop technology to provide a stable surface after mining. Also available technology will not recreate the native mixed prairie vegetative communities within less than 40 or 50 years. A number of basic ecological studies are needed to better understand the dynamics of establishment of these plant communities. Quantitative descriptions of the parameters that determine ecological niches for many of the shrub and woody species needed in these plant communities remain to be developed. In addition we do not know if land reclaimed for grazing will stand up as well as the native prairie vegetation on unmined land under the abuse of over-grazing. Research has been initiated to study the effects of abusive grazing on vegetative and soil stability, but much additional work remains to be done.

CONCLUSION

This paper reviews current ARS research to develop technology to protect the soil and water resources of mined land. Part of this research is supported by an EPA grant to ARS. In the past decade great advances have been made on the development of the needed reclamation technology. Programs and activities presently in progress are defining many of the parameters involved and are providing guidelines by which user groups can make decisions. The information acquired is being used by industry in reclamation practices, by regulatory agencies in enforcing reclamation legislation, by advisory groups serving industry and regulatory agencies, and in extension and educational programs.

It is apparent from this discussion that much has been accomplished. However, much remains to be accomplished, particularly in developing management methods to use after revegetating mined land that will assure long-term sustained protection of the soil and water resources.

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integrated technology assessment

CHAPTER 5

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INTEGRATED TECHNOLOGY ASSESSMENT

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U.S. Environmental Protection Agency

Since 1973, awareness of the close and complex relationship between the Nation's future energy system and its economic, social, and environmental fabric has increased. Although the nature, importance, and reality of the problem of changing our energy system are now recognized, there has been no thorough commitment to the important and expensive task of understanding the implications of alternative energy systems. While no one can predict precisely the full spectrum of implications of energy system choices, much can be done to improve the analysis of the economic and environmental differences between energy system alternatives.

RESEARCH ON EVALUATING THE SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPACTS OF DEVELOPING ENERGY SYSTEMS

The participants in the CEQ/OMB task forces that created the Interagency Energy/Environment Research and Development Program recognized, first, that the relationship between our choice of energy system and our future economic and social structure would have increasing political importance; second, that the Federal Government should support detailed analysis of the implications of energy system alternatives. Therefore the recommendations for the Interagency Program included, as part of the research plan, a section on Integrated Technology Assessments (ITA). The goal of these assessments is clearer definition of the economic, social, and environmental consequences of developing the Nation's energy resources.

Integrated Technology Assessments are not policy development studies but are an appropriate part of the research program. As with other research endeavors, the program products are concepts, methods, and analytical tools. The goal of the program is to improve the procedures used in assessing the implications of alternative energy technologies.

Technology assessment studies start with the specification of the configuration of energy facilities. This configuration includes a detailed description of the energy technology, for example a gasification complex, including mining and transport facilities as well as possible associated electricity or energy generating capacity. Other configurations could include several types of energy technologies or multiple units of one technology in a single geographic location. Often, one of the initial problems for an assessment is developing the precise specification of the technology configuration.

HOW ASSESSMENT ESTABLISHES ITS IMPLICATIONS

Once the configuration is established, the assessment attempts to establish its implications by tracing a number of impacts along chains of cause and effect. As an example, a specific technology implies a change in the inventory of air pollutant emissions. Contributions to the inventory come from not only the energy technology itself but the secondary development it fosters. Air pollutant emissions can change ambient air quality; degraded air quality can, in turn, affect human health and welfare. The impacts of air pollution on welfare may include reduction of productivity of natural or agricultural lands or reduced visibility in scenic areas.

Another example is the impact of the technology on the local economy. This is assessed by calculating the employment needs and the demand for local services created by the facility. These demands are then analyzed in terms of the ability of the local community to supply the needed labor and products or the need to import new people or new skills. Demands for labor and services can alter local economic conditions, such as average income level, type of employment, and residential land values. Energy facilities may also attract manufacturing or other industries needing cheap energy or transportation networks capable of moving nonenergy goods.

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New energy facilities, such as mines or mine-mouth conversion plants, located in sparsely populated areas, will increase economic activity, add to the labor force, augment demand for public services, and provide a potential source of public revenues.

Public or government activities associated with providing services for new development constitute another aspect of the economic impact of energy development.

GENERAL GOAL OF ITA

The general goal of Integrated Technology Assessments is to identify all the economic, social, and environmental consequences of energy technologies and then find a method of analysis that can reasonably describe the size of the impact. This is not easy. Establishing what problems are important can lead to public and political controversy. Questions about the theoretical basis for, or quality of, analytical approaches can lead to erudite and academic squabbles.

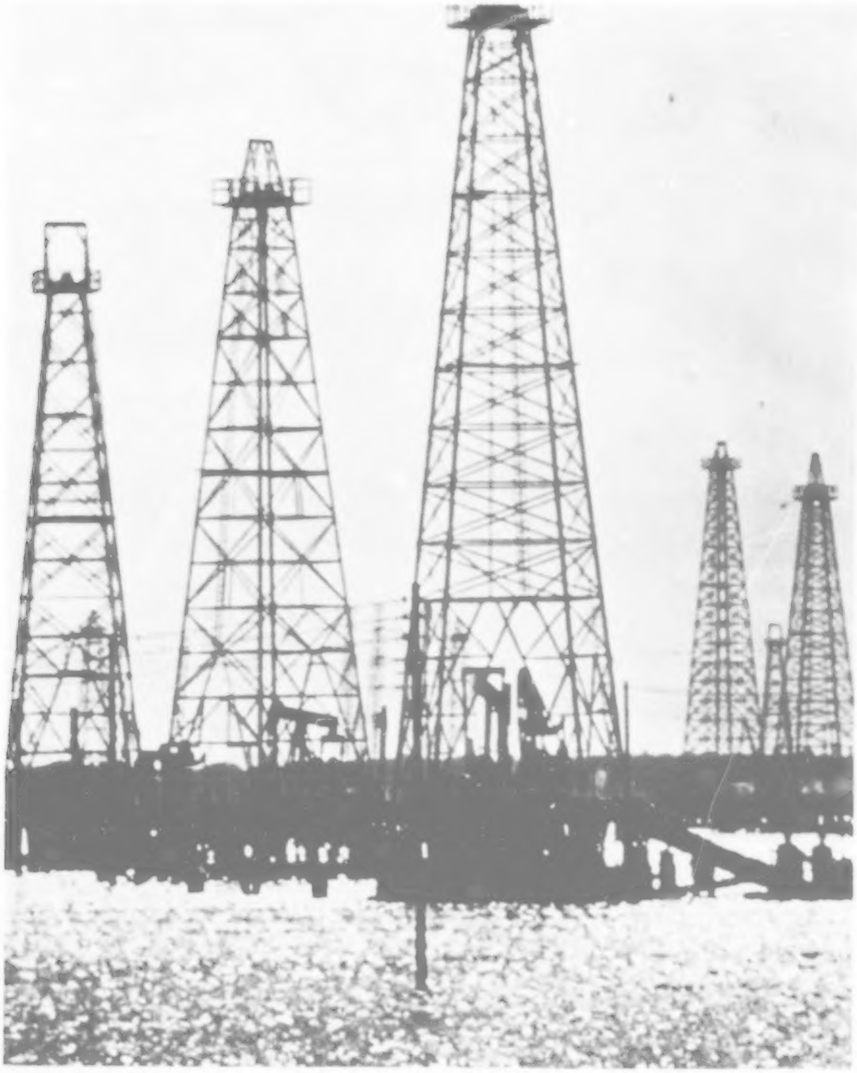
Technology assessments, particularly research on improving the methods of policy analysis, present three major difficulties.

TERMS MUST BE INTERDISCIPLINARY

1. Assessment teams must be interdisciplinary. Any particular issue, for example availability of water resources, will have engineering, economic, institutional, and political aspects—all equally important in assuring a credible analysis. Assessment studies must find ways of using cooperatively the experience, knowledge, and expertise from a wide range of disciplines. Multidisciplinary approaches are essential if impact analysis is to reflect the complexity of real-world issues.

METHODS MUST BE INNOVATIVE

2. Methods used in issue analysis must be innovative. Because the assessment program is a research activity, its important accomplishments will be improvements in the way energy/environment issues are addressed, rather than the analysis results



themselves. The program has, in fact, had its first successes. Models and methods used in several studies are being adopted by others. Three particular studies are worthy of note.

- The EPA-sponsored study of coal-fired electric generation, from the point of view of the individual utility, is being used by the California Energy Commission and the Federal Energy Agency.
- The TVA study of electricity-demand prediction will be used by them in planning new capacity.
- The study of boom-town problems, performed at the Los Alamos Scientific Laboratory/ERDA and partially funded by this program, is gaining wide recognition for its treatment of the problems of small western communities affected by energy development.

ITA STUDIES MUST BE RELEVANT

3. And finally, integrated assessment studies must be relevant. In addition to combining the points of view from many disciplines and at the same time assuring sophistication of approach, the studies must incorporate issues perceived as important by the energy decision-makers and by the people affected by development. In short, the issues considered to be the most important must determine the course of the work. All too often, improvements in analysis methods or theoretical bases for impact assessments tend to usurp the interest of the research team. If this occurs, the effect of assessment studies on "the way things are done" is minimal or long delayed. To assure that assessment studies are relevant, local interests must be specifically included in steering the study. Only by including (through advisory committees, as paid consultants, or by other arrangements) the people who are actually affected by energy decisions can the study teams be sure that their results will not go unread. Actual involvement of the study team in the political process, especially in public hearings, is important and is perhaps essential to assuring the relevance of the study.

There are some very real problems in understanding the economic, social, and environmental implications of alternative energy technologies. In addition to the esoteric questions of socio-economic value, there are some relatively straightforward problems. The amount of information on each energy technology is enormous (Figure 1).

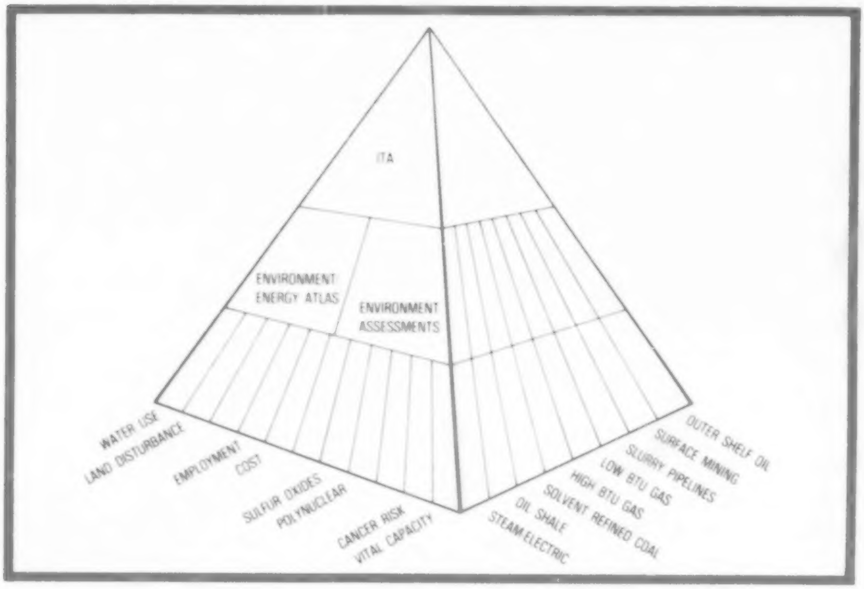


Figure 1.

Implications of energy technologies

A MOST IMPORTANT ITA CONTRIBUTION

For any specific technology, for example high Btu gasification, the facility can have a large number of different configurations. Not only are alternative processes possible, for example fluid-bed versus packed-bed reactors, but alternative pollutant control strategies may be pursued. Alternatives for control include the choice of pollutants and the level of emission limitation. Each configuration has implications for the use of resources—water, fuel, labor, and financing—in meeting a level of energy production. One very important contribution, perhaps the most important, that integrated technology assessment can make is the systematic development and presentation of the performance and requirements of technologies. Because the types of data span a wide range, from engineering costs and employment histories through chemical analysis of emission samples to clinical or bioassay results, integrated assessment studies can provide a mechanism for evaluating comparable data for technology alternatives.

ASSEMBLING AND INTERPRETING A DATA SET

The EPA-sponsored programs include several activities, in addition to the integrated technology assessments, concerned with assembling and interpreting a comprehensive and compatible data set. These activities are an atlas of all western energy development sites and in-depth studies of each of several technologies. The technology studies all devote a large fraction of their resources to pollutant emission measurements at actual energy facilities. The specific aim of the studies is to develop data on the environmental implications of unit process facilities and to document the cost and capabilities of control options. The technology studies focus on the incremental engineering costs for pollution abatement and only secondarily develop information on the characteristics of the energy production facilities themselves. These two study areas, summarized by integrated technology assessments, will start to provide a systematic, consistent, and reasonably comprehensive comparison of alternatives.

Figure 2.

Integrated Technology Assessment Program

- **ASSESSMENTS**
  - **NATIONAL – UTILITIES & ADVANCED SYSTEMS**
  - **REGIONAL – WESTERN, OHIO, APPALACHIAN**
  - **CASE STUDIES**
- **SUPPORT STUDIES**
  - **ECONOMIC PROJECTIONS**
  - **ENERGY PROJECTIONS**
  - **ENERGY DEVELOPMENT REQUIREMENTS**
  - **CASE STUDY METHODS**

The Integrated Technology Assessment area of the interagency program contains two different types of projects. In addition to the assessments themselves, several projects are designed to produce data or models. These studies play a supporting role by providing information or analytical tools to be used by other assessment studies (Figure 2).

The support studies include developing the framework for projecting (either by postulate or by econometric prediction) future levels of national energy use. In addition, support studies have included development of analysis method for defining impacts on regional or local scales. The regional issues include (1) relationship of employment, immigration, and wages, (2) effects of rural energy projects on state and local revenues, and (3) exposition and analysis of boom-town problems. Another area of support study has been a review of the natural resources, specifically land and water, needed to site and operate energy facilities.

PROBLEMS OF REGIONAL OR LOCAL IMPACT STUDY

The study of regional or local impacts has several fundamental conceptual problems. Most of these concern assessing the impact of changing the movement of labor, capital, and facilities in or out of the region. For example, one impact of western energy development will be increased employment in the Ohio River Basin, in the industries manufacturing coal-mining and combustion equipment. Assessing the correct national patterns of increased economic activity, supplying additional mining equipment, and translating this into regional impacts are extremely difficult. In the same vein, assessing any inter-regional transfers, for example out-migration of skilled mining labor, is conceptually difficult. At best, treatment of these impacts requires detailed knowledge of the national situation and knowledge of the relative attributes of different regions in supplying resources to meet a portion of the national demand.

Three studies have addressed local problems. The U.S. Department of Agriculture has examined local impacts both in terms of the relationships between employment, wages, and western in-migration and in terms of the impact of energy development on the structure of public sector financing. The public financing study includes an analysis of changes in fund-raising mechanisms, for example severance and real property taxes, as well as increased demand for public services. The new revenues and demands for services are examined for the major organizations in state and local governments.

Two support studies treat the demand for land and water resources by energy facilities. Competition for these resources, if determined by economic considerations alone, will not lead to conservation. However, capital expenditures can be substituted for both water and land required by energy facilities. EPA is supporting research on water consumption by alternative energy technologies, and the U.S. Department of Agriculture is questioning the utilization of agricultural lands.

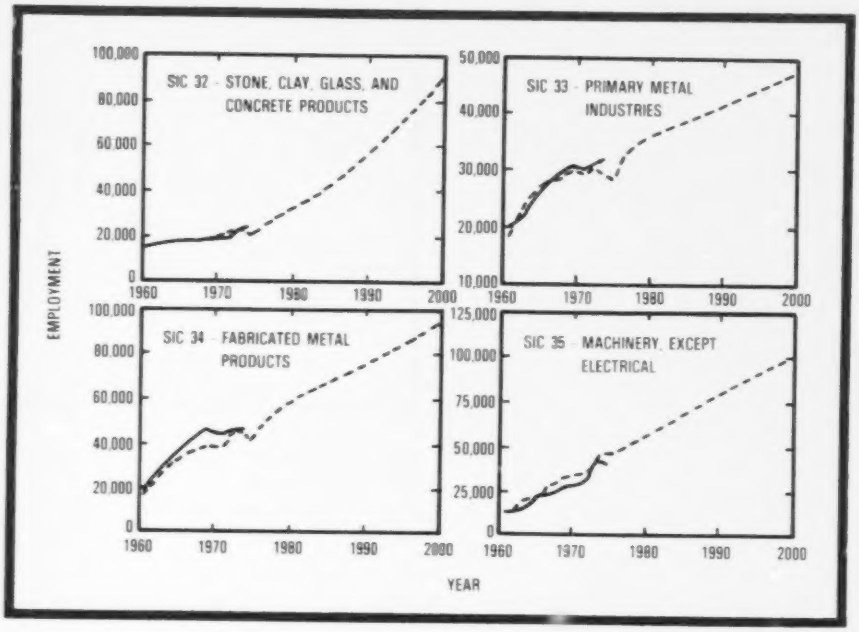


Figure 3.

Comparison of actual and projected employment in TVA power service

ASSESSING FUTURE ENERGY SUPPLY AND DEMAND

The support studies receiving the largest funding are concerned with assessing future energy supply and demand. Both TVA and EPA have projects in this area (Figure 3). The TVA model uses demographic and employment projections to predict electricity consumption. The EPA program uses a large input/output model of the U.S. economy. This model describes the activity of over 100 sectors and relates the exchange of goods and services between these sectors in the production process. Part of the model is a description of the energy demands of both final consumption and industrial/manufacturing processes. The model describes consistently and in a general-equilibrium sense both the demands for energy throughout the economy and the demands of energy production for resources such as steel, labor, and concrete. The model describes the energy supply and demand systems and computes both the costs of energy supply and the pollution impact of the energy supply system (Figure 4).

The EPA portion of the ITA Program includes both regional and national assessments. The projects at the Los Alamos Scientific Laboratory/ERDA are local or small town assessments. Case studies of individual communities or geographic areas are a part of the EPA regional assessments.

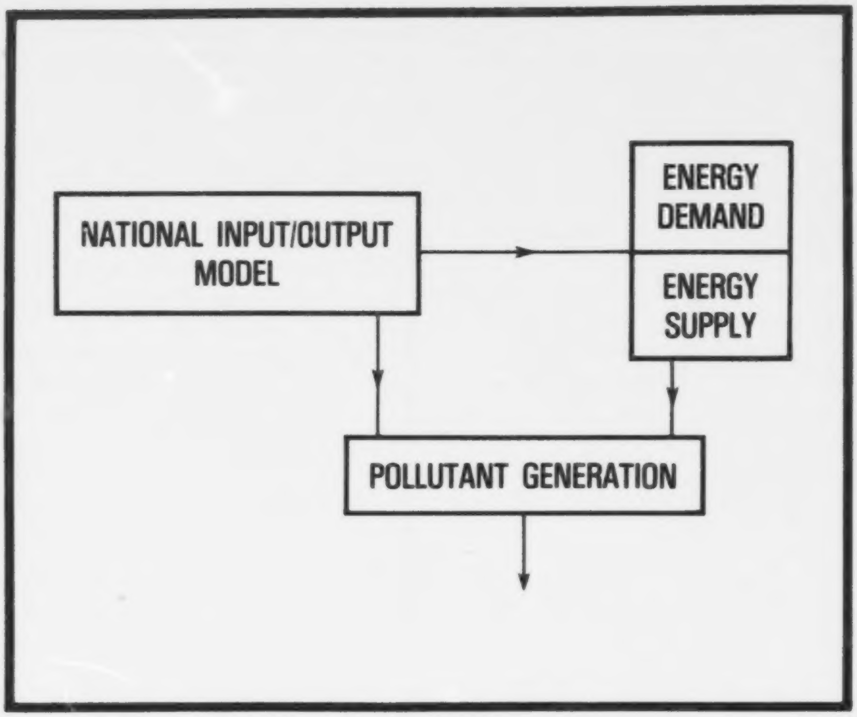
- **FOCUS:**
  ENVIRONMENTAL REGULATIONS ARE COMPLIANCE OPTIONS FOR THE UTILITY INDUSTRY
- **GOALS:**
  ASSESSING ALTERNATIVE REGULATION
- **CONTRACTOR:**
  TEKNEKRON ASSOC.

One of the two national studies is an assessment of the coal-fired steam electric generating industry. This study examines the future of the industry between now and 1990, the period when generation capacity will be by conventional technology. The period after 1990, when new technologies such as low Btu coal gasification will replace conventional combustion, will be examined in a separate project.

Assessment of the steam electric industry is based on a utility-by-utility evaluation of the options for meeting generating demands in compliance with environmental regulations. The study has adopted the perspective of the utility in determining such questions as where to site, when to construct new capacity, how to meet emission limitations, and what types of energy/environment strategies to pursue. The

Figure 4.

Technology assessment modeling (EPA)



information base in support of defining the options available to utilities is very extensive. The study has collected detailed data on (1) availability of power plant sites, including Clean Air Act and water resource issues; (2) source, transportation, and cost of presently developed or new coal mines; (3) interconnections and policies of power grid use; and (4) cost of construction and operation, including pollution control costs, of existing and new generating facilities.

I. COAL FIRED ELECTRICITY PRODUCTION LEVELS

II. NEW PLANT SITING

III. POWER SYSTEM OPERATION

IV. POLLUTANTS AND COSTS

V. ENVIRONMENTAL IMPACTS

This extensive data base and the analysis capability of the study make it possible to address a variety of questions (Figures 5 and 6). (At present, the study results are available for investor-owned utilities. Publicly-owned utilities, accounting for 15 to 20 percent of the Nation's fossil-fuel fired capacity, will be included in the future). The study results include a county-by-county inventory of pollutant emissions.

The sensitivity of the future inventory to such variables as conservation initiatives and economic growth can be compared with alternative control requirements and strategies for their achievement. One interesting result has been the documentation that electricity conservation strategies designed to flatten a utility's load-curve can affect pollutant emissions. If the ratio of peak to off-peak load decreases, the utility restricts the rate at which new generating plants are built. The result is greater utilization of old plants. If utilization of plants now generating 30 percent of the time is doubled, their contribution to emission inventories will double. Many of these older plants are allowed much higher emissions under state implementation plans than those required of new plants. The net effect of load-curve flattening is to reverse the trend toward more tightly controlled generating plants and to allow increases in demand to be met by plants with extremely lax emission standards.

COST CONSEQUENCES OF POLLUTION CONTROL

The electric utility assessment also has generated information on the relative cost consequences of pollution control strategies. The study permits comparison of incremental costs for pollution control (under various levels of stringency in the national standards) with various levels of future electricity demand (Figures 7 and 8). For example, Clean Air Act requirements would add just under $20 per person per year to the costs of generating electricity in 1990 (current dollars). A national coal cleaning industry could reduce the costs by 15 to 20 percent. Strict new-source controls requiring a scrubber on every new plant would increase the annual costs to about $25 per person. A strict retrofit program could increase costs to $35 per person.

Assuming strict emission controls, a strict conservation program could reduce the annual costs of electricity production by as much as $45 per person, and a program to

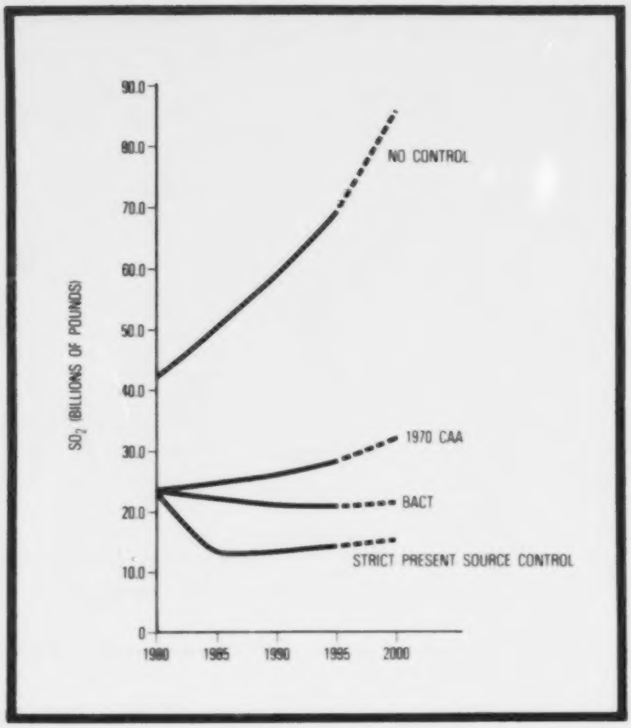


Figure 5.

How will progressive controls affect nationwide SO_2 emissions?

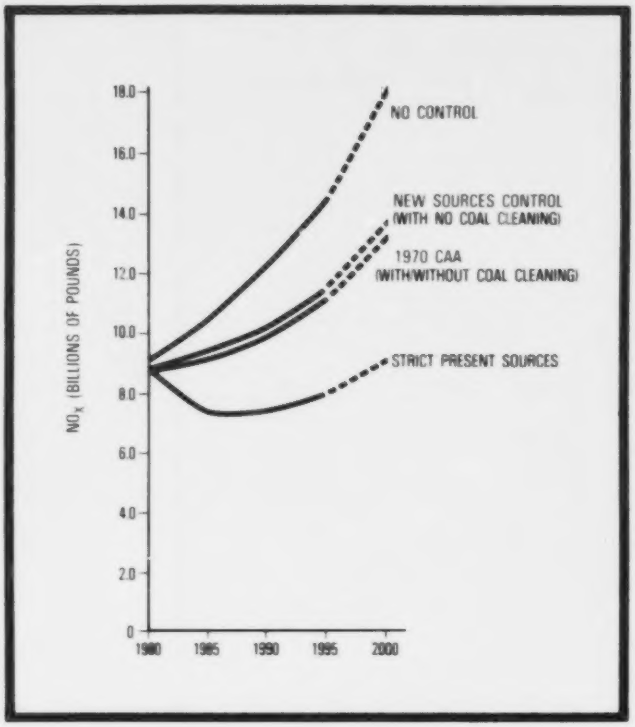


Figure 6.

How will progressive controls under reference energy future affect NO_x emissions?

increase coal use and reduce petroleum fuels could increase annual costs by $12 per person. Very much higher costs for electricity generation would result if electric-powered transportation was substituted for the internal combustion engine.

The national assessment is also able to review the projections of alternative coal resource use and the effect of pollution controls on coal transportation. The sulfur dioxide control requirement can change the relative cost of Eastern, Central, and Western coals. However, use of low sulfur Western coal will grow more rapidly than that of either Eastern or Central reserves (Figures 9 and 10).

THREE REGIONAL TECHNOLOGY ASSESSMENT STUDIES

In addition to the national assessments, EPA is sponsoring three large regional technology assessment studies (Figure 11). Each of these three studies is tied to coal resources and each will be conducted in a manner which assures involvement of the parties affected by and concerned about energy developments. The initial phases of two of the regional studies—the Western and the Ohio River Valley assessments—have been completed. The studies have defined the future technology configurations they wish to study and have clarified the issues, problems, and questions most important to the region. The depth of analysis given to the issues thus far varies, but in general the Western assessment has progressed well on all issues except those concerning the institutional or political consequences of energy development.

The Appalachian regional assessment has just been initiated.

WESTERN ASSESSMENT

The Western assessment concerns both the northern Great Plains and the Four Corners fuel reserves (Figures 12 and 13). The study treats issues on at least two geographic scales. Water supply, visibility, and financing public services exemplify issues that must be studied on a state or regional basis. Air quality, reclamation, and boom-town effects are studied in terms of six example locations.

Many specific issues are defined and analyzed, and this report cannot attempt to summarize the technology assessment. However, certain selected results can be used to indicate the nature of the studies.

Figure 7.

Per capita costs in 1990 with related emission reductions under progressively strict controls

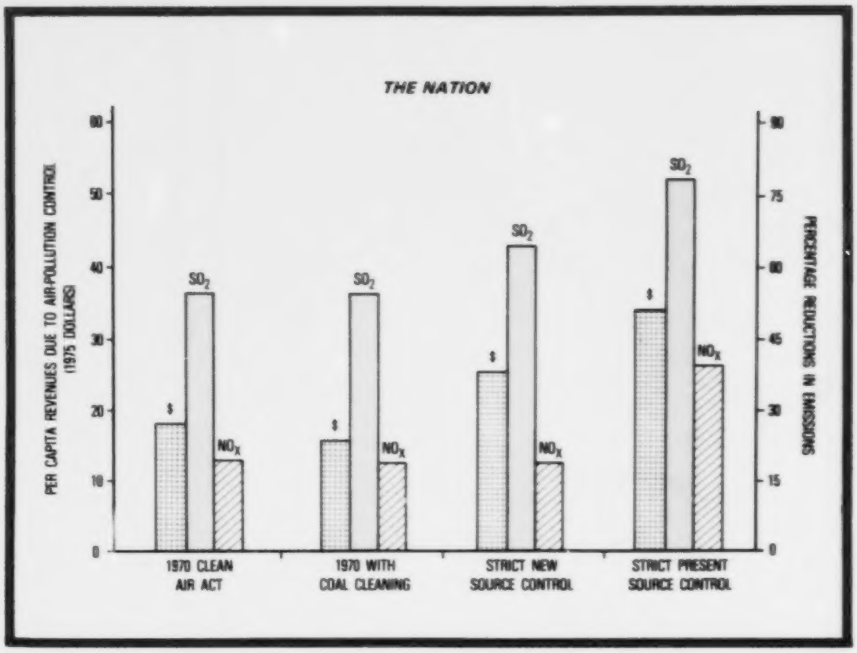


Figure 8.

Per capita costs in 1990 with related emission reductions under strict environmental controls

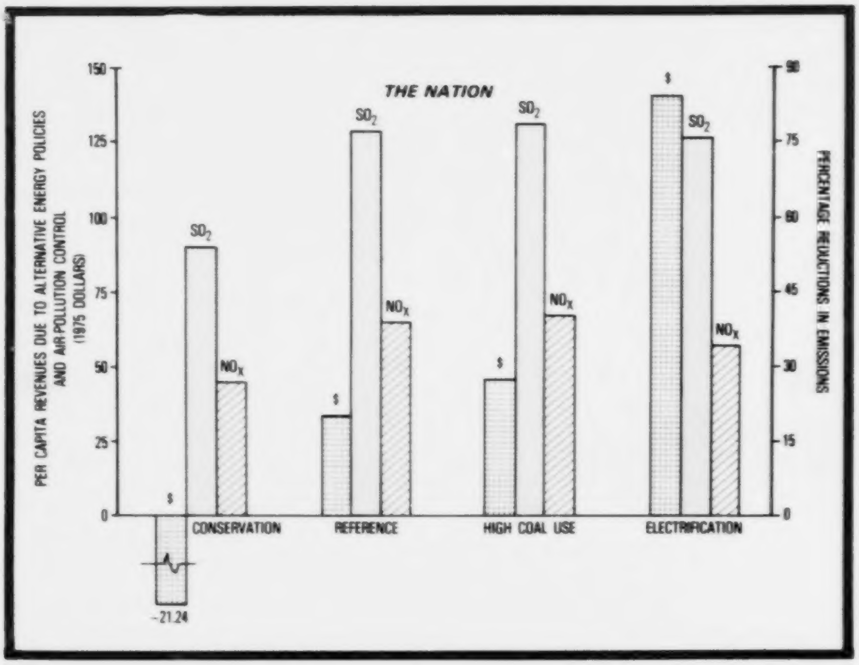


Figure 9.

Percentage of U.S. Coal Production by region and percentage distribution of regional coal (1975)

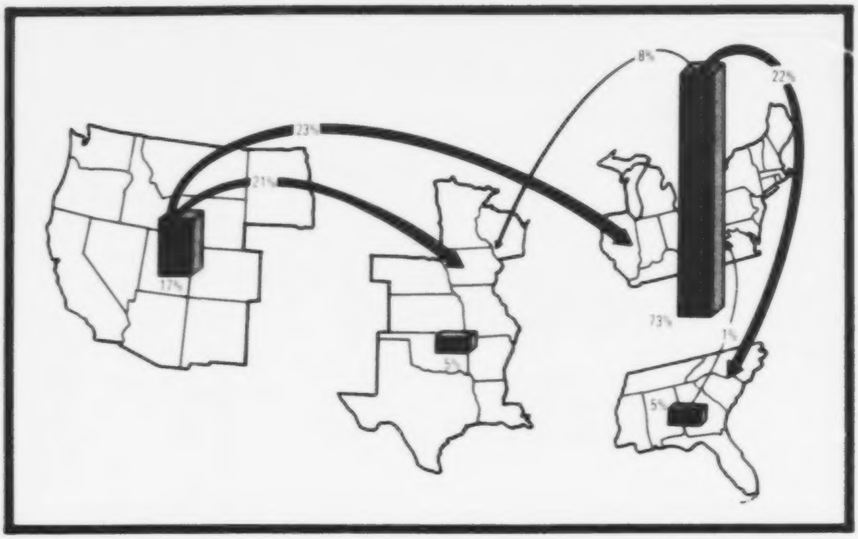

8%
22%
23%
21%
17%
5%
73%
1%
5%

Figure 10.

Percentage of U.S. coal production by region and percentage distribution of regional coal (1990)

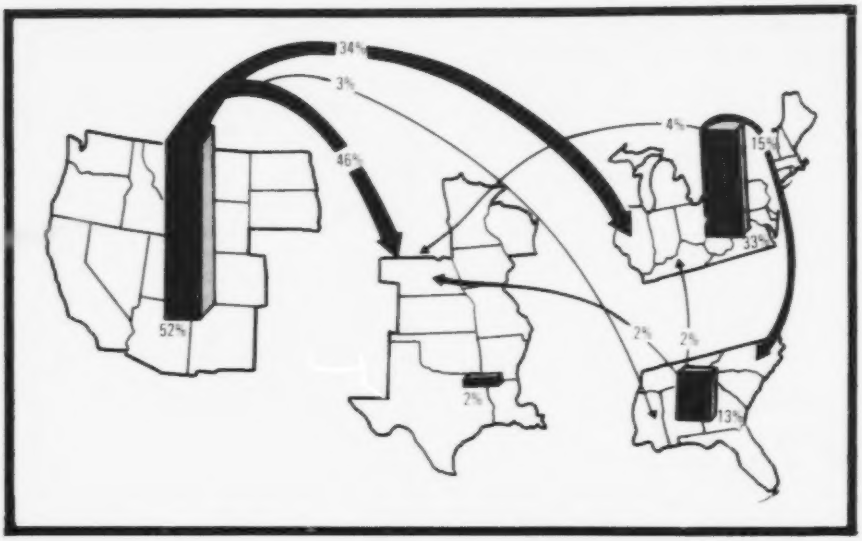
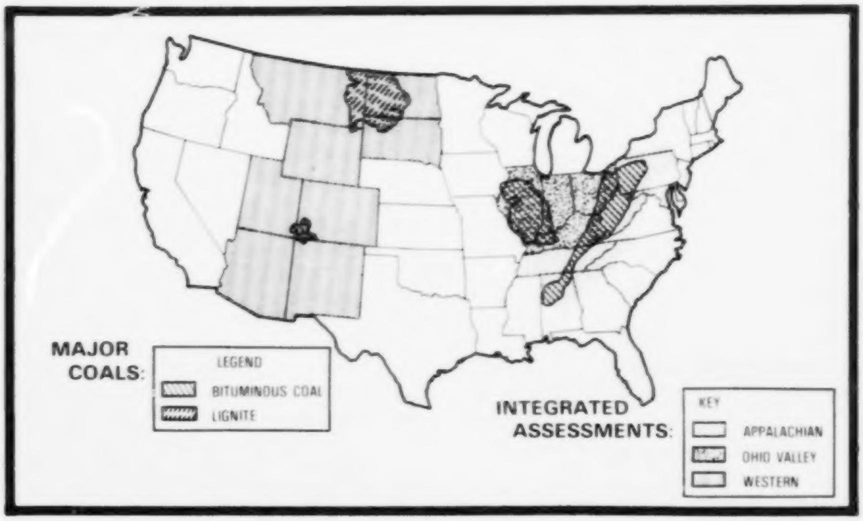

34%
3%
46%
4%
15%
33%
52%
2%
2%
2%
13%

Figure 11.
Regional integrated assessments


MAJOR COALS:
LEGEND
BITUMINOUS COAL
LIGNITE
INTEGRATED ASSESSMENTS:
KEY
APPALACHIAN
OHIO VALLEY
WESTERN

FOCUS:
COAL AND OIL SHALE
1975-2000
NORTHERN GREAT PLAINS, FOUR CORNERS
FUEL CYCLE FROM EXTRACTION TO TRANSPORTATION
RESEARCH TEAM:
SCIENCE & PUBLIC POLICY PROGRAM UNIVERSITY OF OKLAHOMA
RADIAN CORPORATION, AUSTIN, TEXAS
APPROACH:
CRITICAL FACTORS ANALYSIS
SIX SITE SPECIFIC SCENARIOS
REGIONAL SCENARIO, 3 DEVELOPMENT LEVELS

Figure 12.

Technology assessment of western energy resource development

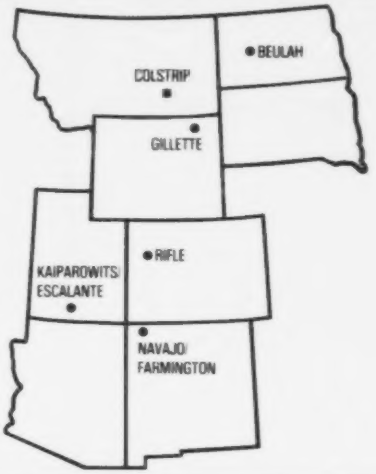


Figure 13.

Northern Great Plains and Four Corners fuel reserves

Figure 14.

Manpower requirements for energy facilities (per 10^{15} Btu/yr)

	TOTAL MAN YEARS	RATIO: CONSTRUCTION TO OPERATION
GASIFICATION	58,500	8.1
LIQUEFACTION	36,300	1.7
NATURAL GAS PRODUCTION	27,700	2.2
CRUDE OIL PRODUCTION	26,100	1.9
OIL SHALE RETORTING	14,500	4.1
POWER PLANT		
THERMAL	11,600	5.8
ELECTRIC	34,200	

Alternative technology configurations will have differing implications with regard to in-migration of labor and accommodation of transient labor (Figure 14). Data on the employment necessary to construct and operate various energy technologies have been analyzed. For each unit of energy production, coal gasification creates the largest number of jobs. However, the number of temporary jobs created by the construction of the gasification facility is 8.1 times as large as the permanent operating work force. Oil shale retorting will employ one-fourth as many people as coal gasification for equal levels of energy production. In terms of permanent employment, however, oil shale will create half the number of jobs.

CONSUMPTIVE AND EVAPORATIVE WATER USE

The consumptive or evaporative water use for energy depends upon many factors—the energy technology, whether the technology is designed to conserve water, and the local conditions (Figure 15).

Wet/dry combined cooling towers will always reduce water consumption as compared with wet cooling towers—at a cost, however. Coal gasification, which uses water as a chemical and for thermodynamic properties, requires less water than conventional combustion and steam-cycle electricity generation. In addition, the local conditions, including climate and the moisture content of the coal, will affect water consumption. Beulah, Montana, has cold weather much of the year, and the coal in that region has a high moisture content. Gasification using wet/dry cooling will require only one-tenth of the water necessary to produce an equivalent amount of electric energy using conventional steam cycles and wet cooling towers.

Water resources, even with required measures to reduce consumptive use, will be a problem for the Colorado River Basin (Figure 16). Realistic levels of energy development in the Upper Colorado Basin can use all the available water resource by the end of the century.

COLORADO BASIN WATER SUPPLY–COMPLEX ISSUE

Water supply in the Colorado Basin is an extremely complex issue. Although supplies have been allotted by Supreme Court ruling to the Upper Basin States, this water is now being used in the Lower Basin. Energy development in Colorado will mean less water in southern California. Water quality (that is salinity and hardness) and Indian water consumption are other issues complicating the development of water-using industry in a water-short region.

AIR QUALITY AND PRESERVATION – CRITICAL PROBLEM

Air quality and its preservation are also extremely critical problems in the Western States. Because of the concern over air quality, both federal and state air pollutant emission controls can be more stringent here than elsewhere in the U.S. Some western sites, such as Rifle, Colorado, and Escalante, Utah, will require extremely stringent control practices to assure maintenance of air quality (Figure 17).

Because of the history of the area, its energy reserves, its present level of industrialization, and its transportation corridors, the Ohio River Valley will experience the politics of energy and environment trade-offs. Projections for the area include as much as a four-fold increase in coal use for an area that already has severe air quality problems (Figures 18 and 19). Power plants and industries will locate along the major waterways. Unfortunately, these river corridors lie along the direction of stable prevailing winds, and both local and area-wide pollutant concentrations will increase.

Figure 15.

Water requirement differences by technology and location

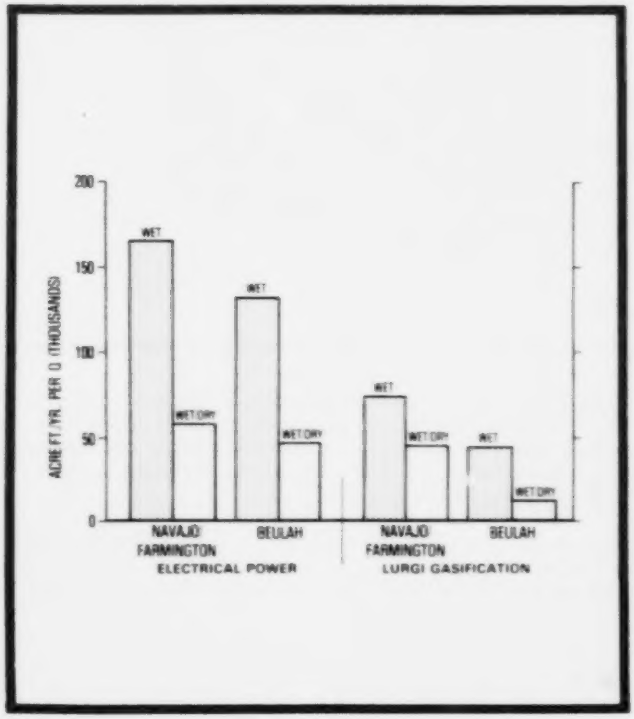


Figure 16.

Water requirements and water availability–A.D. 2000

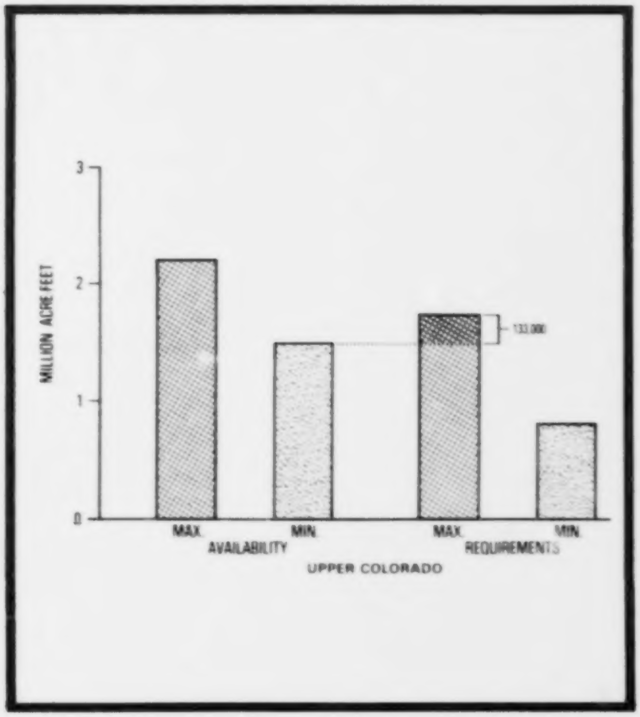
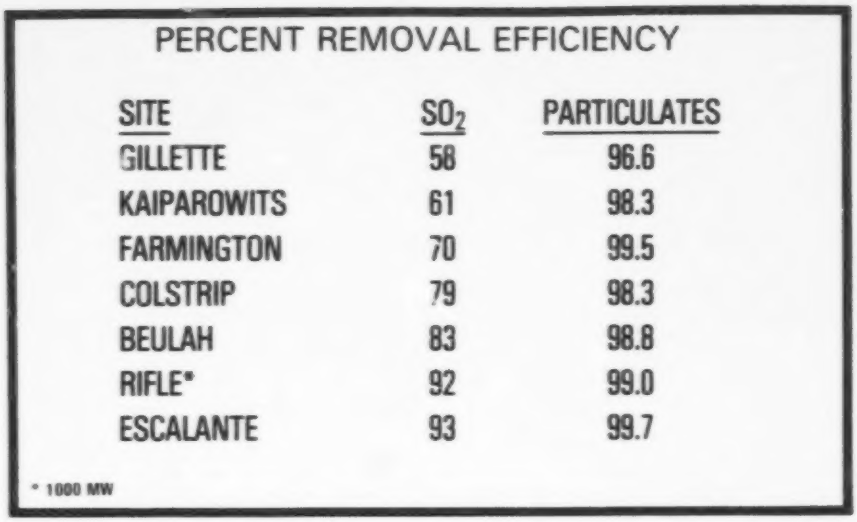


Figure 17.

3000 MW power plant: controls to meet all standards



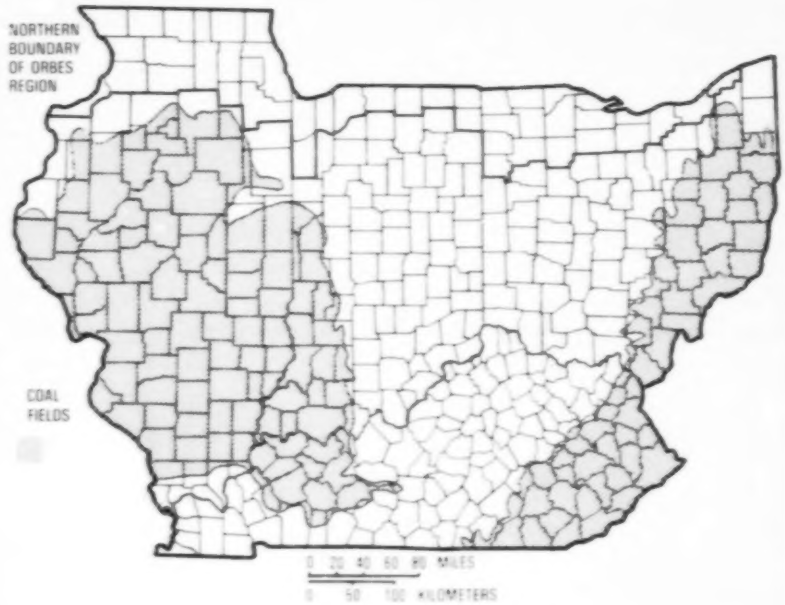
PERCENT REMOVAL EFFICIENCY

SITE	SO_2	PARTICULATES
GILLETTE	58	96.6
KAIPAROWITS	61	98.3
FARMINGTON	70	99.5
COLSTRIP	79	98.3
BEULAH	83	98.8
RIFLE*	92	99.0
ESCALANTE	93	99.7

* 1000 MW

Figure 18.

ORBES region—coal fields



A principal use of the Ohio River is transportation. Power plants consume water and, by the end of the century, could reduce mainstem flows by more than 10 percent. Because of the complex flow regulation on the Ohio River, coal transport, water quality, and cooling consumption will begin to compete for water supplies on one of the Nation's largest rivers (Figures 20 and 21).

The Ohio River Basin study is examining a range of other issues, including labor availability, transportation system capacity, and the impact of sulfur dioxide control programs. The analysis of many of these issues will be available after this conference.

Figure 19.
High density corridors resulting from siting along rivers

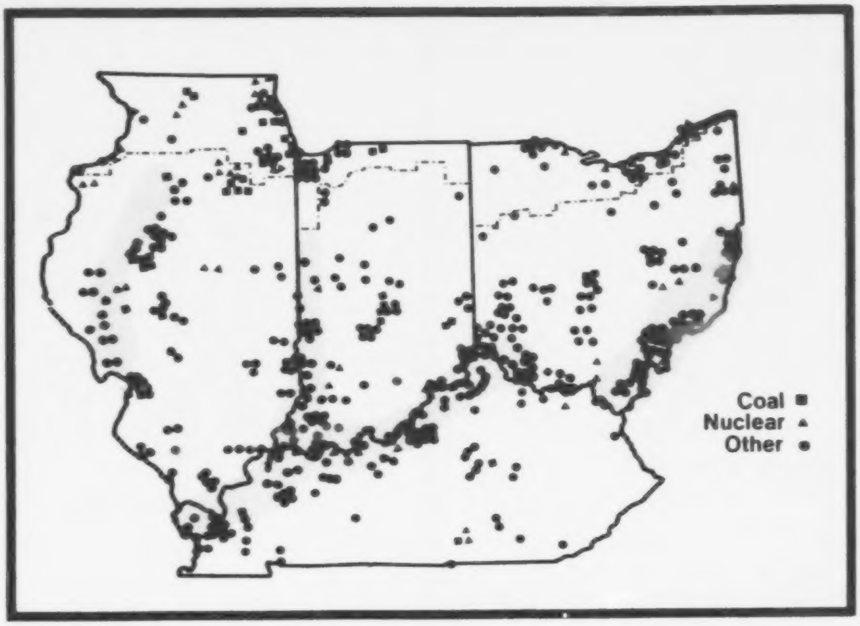

Coal ■
Nuclear ▲
Other ●

Figure 20.
1990 Ohio River coal traffic

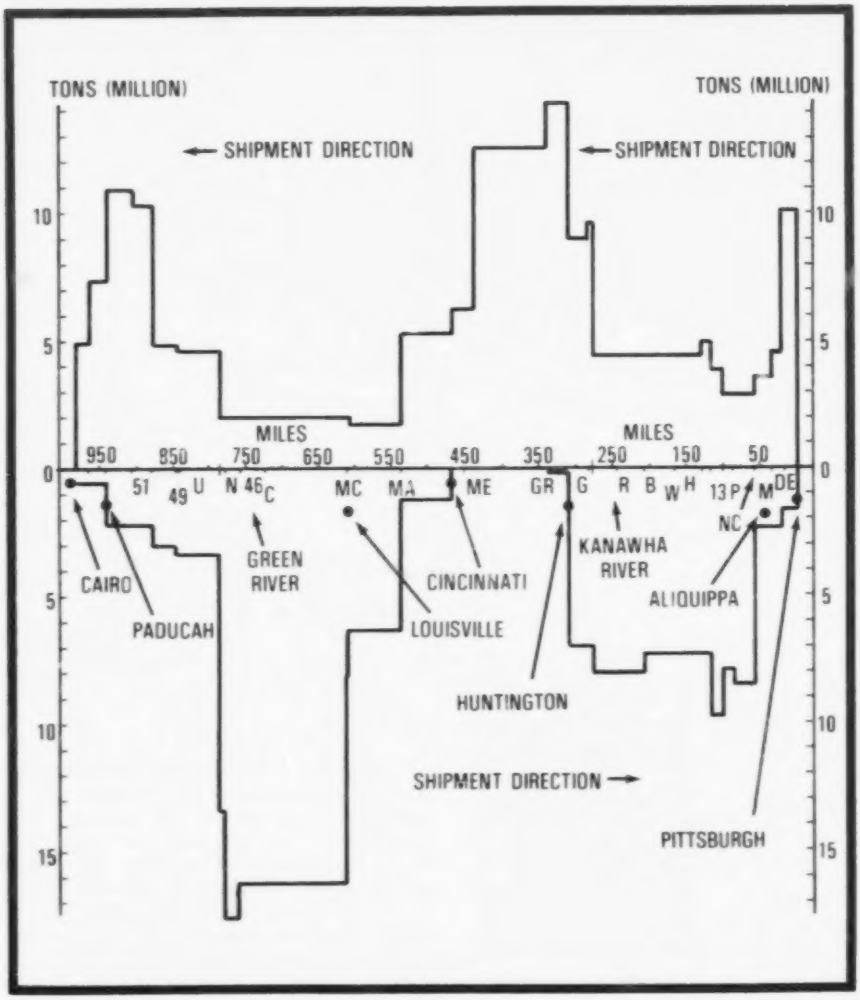
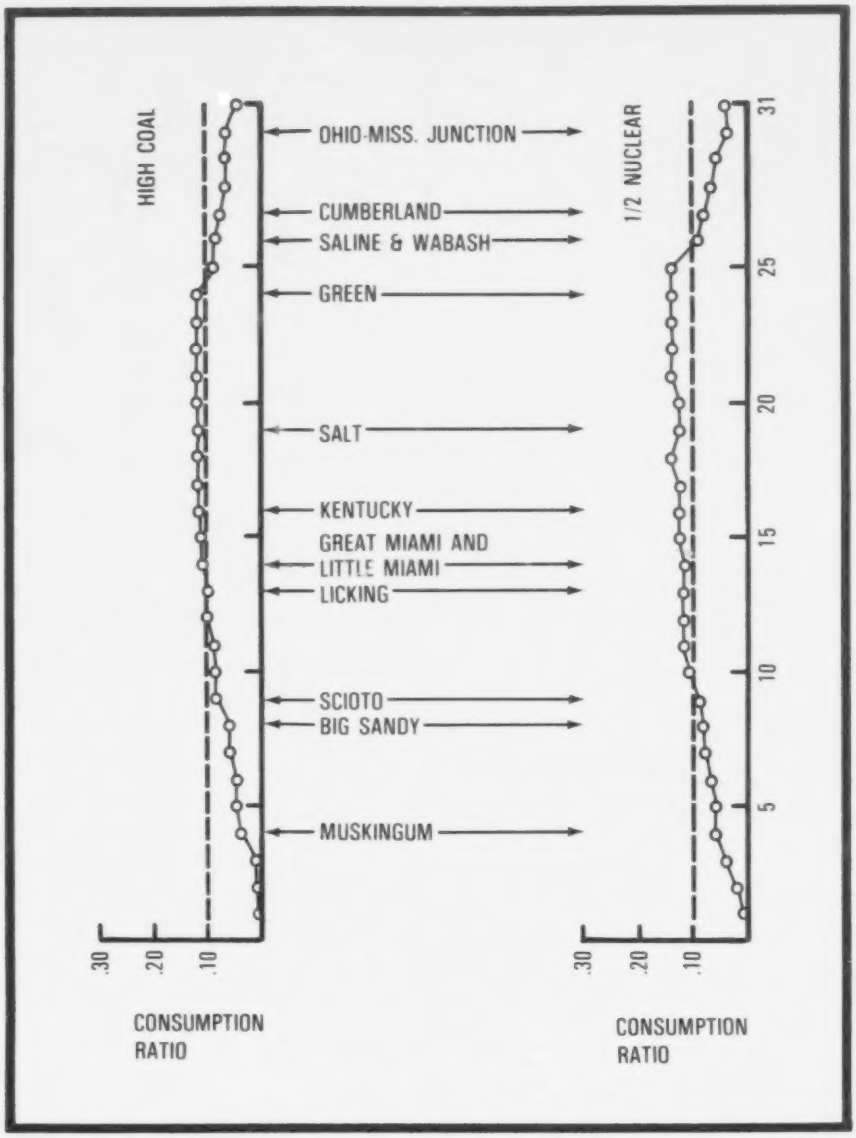


Figure 21.

Water consumption along the Ohio River for high energy use in 2000



STEVEN R. REZNEK

B.S. and Ph.D., Physics, Massachusetts Institute of Technology. Upon completion of Ph.D. requirements, was employed by MIT as a research associate. Also held staff position and continued his research at the Technical University of Denmark in Copenhagen. The following year, was appointed research fellow at the University of Bristol in England. Experience in research and development for pollution control technology and in planning and managing air and water pollution control. Participated in creation and publication of major EPA regulations specifying ambient and stationary source monitoring equipment, lead content in gasoline, and nondeterioration of air quality. Currently, Acting Deputy Assistant Administrator for Energy, Minerals and Industry, Office of Research and Development, EPA, Washington, DC.

questions & answers

Mr. Charles Getlig
Mechanical Engineer

Mr. Nathan Sauberman
Retired Consulting Engineer

Dr. Edward S. Rubin
Carnegie-Mellon University

QUESTION: On your two slides showing NO_x emissions and sulfur oxide emissions, despite the strict control, why do you show an increasing trend after an initial decrease to a low level? Also, why do you have an increasing trend toward the end of the century?

RESPONSE: **Dr. Steven R. Reznek (EPA)**

Those controls are based on best available technology, and the first decrease is the strict current source control retrofit program. Assuming that the status of control technology remains constant, there is an increase as the energy system grows and production of electricity increases over a period of time.

The other slide indicates the time frame we have to work with for managing and maintaining the national inventory of emissions from this particular industry under current technology.

QUESTION: Can you give me some more information on an Advisory Commission with public participation?

RESPONSE: **Mr. Lowell Smith (EPA)**

On the Ohio River Basin (ORB) study, we have a comprehensive advisory committee that includes representation from the Governor's offices from the ORB states and from the state legislatures involved, the Corps, Ohio River Valley Water Sanitation Commission, (ORSANCO), the River Basin Commission, coal companies, utilities, and the public-at-large; such as, the League of Women Voters and environmental groups. This advisory committee has been instrumental in determining the issues of interest to be studied during this first year of the ORB study and has also been an effective information transfer device between the different parties of interest.

We have what we call a working group of electric utility representatives who give us their advice and thoughts on the need for different types of control technology. This group advises the program that Frank Princiotta presented this afternoon.

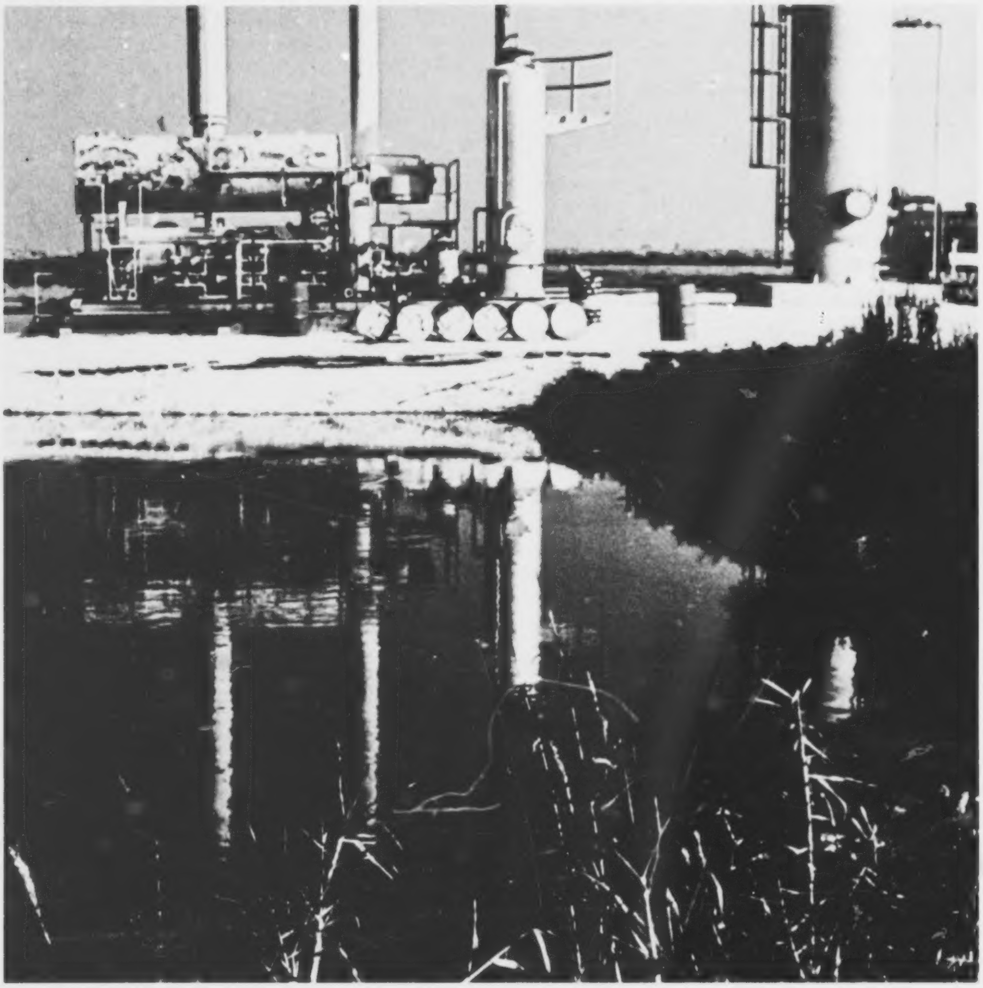
RESPONSE: Mr. Steven Plotkin (EPA)

Both our western study and Appalachian study have advisory committees. The Appalachian Committee is still in the formulation process. However, both are similar in composition to the one that was described in the ORB study.

In addition, there are a number of other mechanisms by which we try to elicit public comment. First, there is an excellent newsletter published by the ORB study that serves as an information tool to people in that region. The western study prints and disseminates 500 to 1,000 copies of all draft reports. We have been very successful in getting free consulting from people who have returned from the field. For instance, out of 500 copies of our draft progress report, we have had about 100 substantive replies that we have used as input for our study and final report. The whole program is very new, and we are trying our best to involve the public in every possible way.

COMMENT:

Dr. Reznek did mention the implications of the social impact of the program, and I think such an advisory commission would be very worthwhile.



RESPONSE: Dr. Reznek

We have a wide representation on these advisory groups, including the native American issues in the West. Questions of who gets employed and who loses land in these developments are, as you know, very controversial issues. Through our advisory committees, open discussions and open reviews take place. Dr. Hickey, do you want to talk about TVA's participation in predicting demand?

RESPONSE: Dr. Harrison R. Hickey (TVA)

We have two projects in the socioeconomic category. One is the predictive model designed to help predict when, where, and how much power is going to be needed. The other involves the development of computer graphics applications to discern and analyze social impacts; such as, the impacts on teachers' salaries on a county-by-county basis. It is purely an experimental project, but we have come up with unique ways of representing these interactions for decision-making purposes.

QUESTION:

My question is three-fold: (1) Can methodologies be generalized to accomplish results typically achieved through the political mechanisms? (2) How do we make tradeoffs? (3) How do we improve the ability to integrate certain types of decisions and what activities are contemplated?

RESPONSE: Mr. Joseph R. Barse (USDA)

I would like to respond to the question of methodology integration for energy development impact. Because there are so many potential impacts involving so many variables, one has to use a mathematical modeling approach, which of course will be applied by computer. First, consider demand studies and electricity use. If with electricity and electricity plant siting projections we work backward to estimate the possible locational impacts of coal mining and coal transportation in order to get control of the socioeconomic impact, such as, employment, and state taxation impact, we can then talk intelligently about the quantities of pollutants involved in streams and about whose land is going to be taken for mining and for transport. Because there are so many variables involved, we believe that the mathematical modeling approach is the way to achieve this integration. It is a longer way than the nonmathematical approaches and it takes more time to develop it, but we believe that ultimately that is the way to do the integrating.

RESPONSE: Dr. Thomas F. Hady (USDA)

I would like to comment on possible results of ongoing projects in this area. We have made considerable progress in directions that have not been heavily explored before. On the one hand, looking at local employment effects from energy development in the West and, on the other hand, getting at local revenue effects involve modeling the entire state revenue system. It is not enough to find out what kind of taxes mining will pay; we have to determine what is going to flow up to the state capital and back again.

These factors eventually fit into an integrated picture of what happens to the community. With these and the work that Barse and his associates are doing on predicting what will happen to coal production in the region under varying assumptions, we begin to move toward an overall package that gives a good integrated assessment of what is likely to happen. Put that together with the other work that is being done, and we can get to the point of beginning to predict environmental effects.

RESPONSE: Dr. Andrew Ford (ERDA)

We tried multianswer utility measurement in the boom town area to secure people's value judgments in the analysis. Our first attempt to integrate socioeconomic effects with dollar measures was an utter failure, and so we turned to this multianswer utility measurement technique that allows each person's values to be incorporated separately. The problem we face is that we would have a particular impact in a small town; for example, a housing shortage. One person would view that as bad because of inadequate housing for his family, and another person who may own a house would view the shortage as a benefit because the resale value of his house goes up. We had a workshop in Farmington, and nine public and private officials went through a procedure where they stated what is important to them about boom towns. To one person, housing was the most important issue; to another, increase in the property tax rated number one. Each person has his own set of weights, his own way to translate outcomes into common measures.

The end result was that these nine participants disagreed totally on individual components of an overall evaluation. One person felt that surpluses of public facilities are bad. The person sitting right next to him viewed them as good. And so, there is a tremendous potential for conflict, and yet, in the overall evaluation, this group of people in Farmington tend to agree more often than they disagree. So perhaps this technique is one method to promote an orderly resolution of very emotional issues at the boom town level.

technical discussion

INTEGRATED ASSESSMENT OF ENERGY DEVELOPMENT IN THE WESTERN U.S.

Steven E. Plotkin
Office of Research and Development
Industrial and Extractive Processes Division
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Washington, D.C.

INTRODUCTION

Two important ideas about energy development in the Western United States have become firmly imbedded in the national consciousness. The first is that the West has massive amounts of energy resources, especially coal, and that development of these resources is a critical part of any hopes of alleviating this country's growing dependence on foreign oil and is therefore inevitable. The second is that this same area is "Big Sky" country, short of water and fragile of soil, with an environment and a way of life that may become permanently altered, or even destroyed, by large scale energy development.

In fact, considerable uncertainty surrounds both of these ideas. Let's examine the role that Western energy resources are likely to play in the Nation's future. It is certainly true that Western energy reserves are huge. The combined Northern Great Plains and Four Corners States have demonstrated coal reserves of 234 billion tons or 39 percent of U.S. reserves. In addition, these states contain the following percentage of the Nation's reserves of other energy sources: oil, 26 percent; natural gas, 8 percent; oil shale, 100 percent*; and uranium, 90 percent (Reference 1). However, although this appears to be an energy treasure trove, the extent to which these resources will actually be exploited eludes the best forecasters. In recent years there have been dozens of projections of Western energy development, but they vary so wildly that they offer little help. A quick examination of two factors affecting future production illustrates the dilemma:

- Environmental Controls - The major advantage of Western coal is its low cost and low sulfur content. If this coal is shipped to the Midwest, its cost rises because of the shipping expense. However, it still remains competitive if Midwestern power plants can burn it without scrubbers. New amendments to the Clean Air Act may include a requirement for all new coal plants to use scrubbers; if this happens, a major market for Western coal will disappear.
- Costs - Synthetic natural gas and petroleum from Western coal and oil shale will have a certain market if these fuels can be produced at competitive prices. At present, the estimated costs for such production are so high that virtually all of the large-scale synthetic fuel projects have been abandoned. Congress has turned back all attempts to subsidize synthetic fuels production.

The uncertainty surrounding these and other factors controlling the rate of Western energy development substantially weakens the case for the "inevitability" of development.

The assumption that the West is too fragile to withstand energy development on any significant scale is also subject to considerable uncertainty. For instance, although Western water is certainly scarce on the average, water is actually plentiful in North Dakota, where there are massive lignite reserves, and may be available to support substantial development in the Upper Missouri River Basin without seriously constraining foreseeable alternative uses, especially agriculture. Although boomtowns are commonly thought of as inevitable in developing the West, recent research by David Myhra (Reference 2) suggests that the intensity of adverse socioeconomic impacts is quite variable and may be low depending upon characteristics of the site and mitigating measures adopted. Also, the impacts of energy development-for instance, impacts caused by water requirements - are technology-dependent, which implies that technological alternatives may have the potential to be "fitted" to sites so as to substantially reduce adverse impacts. There is real reason to believe that policy initiatives may be found that can substantially reduce the impacts of development.

These two themes, that future energy development in the West is subject to massive uncertainties, and that potential may exist to control many of the adverse impacts from such development if it occurs - have played a substantial role in shaping the thrust of the Western energy research sponsored by the Integrated Assessment Program. As a result of the uncertainty regarding development rates, the research deliberately sidesteps the intractable problem of projecting development and instead examines the implications of such development if it occurs. The perceived potential for discovering ways of controlling adverse impacts has led to focusing on the examination of policy alternatives rather than concluding with problem identification, as so many other studies have done (for example, the Northern Great Plains Resources Program).

Another influence shaping the research is the nature of the energy policy system. The policy system that surrounds and controls energy development in the West is characteristic of the national energy policy system in that

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* Of high quality reserves

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it consists of a great variety of separate entities with overlapping and often conflicting responsibilities and authority. The Environmental Protection Agency (EPA), although it has significant regulatory authority over certain factors affecting Western energy development, is by no means the sole determinant of the course of such development. For instance, in protecting the air environment EPA:

- sets national ambient air quality standards for a variety of pollutants
- can set limitations on other pollutants determined to be "hazardous"
- establishes New Source Performance Standards that determine allowable levels of emissions from new facilities
- conducts extensive research on control technology and pollutant impacts
- sets limitations on allowable deterioration of air quality in "clean air" areas
- reviews Environmental Impact Statements for new facilities and programs
- plays a key role in controlling pollution from automobiles, which play a critical role in pollution problems from the "secondary" development that accompanies energy facilities

Although this is an impressive list of functions, in fact the protection of the West's air environment is simultaneously dependent on factors outside of or peripheral to EPA's control. For instance, the States control many of these factors; they control key facility siting decisions, set significant deterioration classes, promulgate ambient air quality standards, take crucial enforcement actions, and are responsible for air quality planning through their State Implementation Plans. Other actors, such as private industry and the Department of the Interior also play critical roles in influencing development decisions affecting air quality. Thus, if EPA is to fulfill its mission, it must understand how the other actors in the policy system will perceive and react to problems and issues and how its own actions will affect these actors and their constituents. In response to this requirement, the research has focused on identifying and evaluating a broad range of impacts and policies going well beyond strictly environmental concerns and incorporating socio-economic, political, cultural and institutional concerns as well.

A brief statement of the objectives of this research effort is as follows:

1. To identify and evaluate the consequences likely to result from energy development in the West, including the distribution of these consequences among the affected parties
2. To identify, evaluate and compare alternative policies and implementation strategies for dealing with these consequences
3. To identify research needs that are not being adequately met under the present government and private energy and environmental research efforts

PROJECT DESCRIPTION

This effort is entitled "A Technology Assessment of Western Energy Resource Development." It was begun in July, 1975, by an interdisciplinary research team from the Science and Public Policy Program of the University of Oklahoma under the direction of Irvin L. (Jack) White. The study will last about three and one half (3 ½) years at a cost of approximately two million dollars. Subcontractors include the Radian Corporation (Austin, Texas), Water Purification Associates (Cambridge, Mass.) and the Center for Advanced Computation, University of Illinois.

The study is examining the impacts of large scale energy development from the present to the year 2000 in the eight states in the Rocky Mountain and Four Corners area: Arizona, Colorado, Montana, New Mexico, North and South Dakota, Utah and Wyoming. Six resources are examined: coal, geothermal, natural gas, oil, oil shale and uranium.

A number of development alternatives have been considered in detail during the first phase of the study. Coal development alternatives include surface and underground mining, on-site electrical power generation, gasification, liquefaction, and the export of raw coal by unit train and slurry pipeline. The electricity is transmitted by extra high voltage lines, and synthetic gases and liquids by pipeline. Oil shale development consists of underground mining, surface retorting, and transport by pipeline (in situ retorting will be considered in the future). Oil and natural gas development is limited to conventional drilling and pipeline transport, but enhanced oil recovery will be added. Uranium development includes surface mining, milling, and rail transport of yellowcake. Geothermal was not considered in the first phase but will be added shortly.

Impact analyses have been conducted at six locales and on a regional basis. The locales examined are multicounty areas around:

- Gillette, Wyoming
- Colstrip, Montana
- Beulah, North Dakota

- Kaiparowits/Escalante, Utah
- Navajo/Farmington, New Mexico
- Rifle, Colorado

The regional analysis examined three levels of development based on a modeled (using the SRI/Gulf model) response to three levels of national energy demand:

- Base: 30 percent of the way between the Ford Foundation's Historical Growth and Technical Fix scenarios (Reference 3)
- Ford Foundation's Technical Fix Scenario
- Base with no new nuclear plants

SOME STUDY RESULTS

The study team has basically completed the "impact assessment" portion of the study. The purpose of this phase was to identify and evaluate the environmental, social and economic impacts of large scale energy development within the present policy system, in other words, without changing environmental standards, introducing new taxes, or taking other new measures to alter the impact of development.

A number of insights have been gained and tentative conclusions drawn at this point in the study. Because of the limitations of space here, I will restrict the discussion to air and water impacts, and substantially shortchange even these subjects. I urge those interested in these and other categories of impacts to read the project's first phase report, Energy from the West (Reference 1).

Air - Although the attractiveness of Western coal has been largely based on its low sulfur content, mine-mouth power plants located in the West will generally require scrubbers to satisfy all ambient air quality and emission standards. Present standards to prevent significant deterioration of air quality ("PSD" standards) are often the limiting factor; in the range of sites examined in the study, 96.6 to 99.7 percent removal of particulates and 58 to 92 percent removal of sulfur dioxide is expected to be required to meet Class II PSD standards (all areas complying with national ambient standards have been initially rated as Class II). Power plants present a relatively difficult problem with regard to air quality, since they emit more SO_2, particulates, NO_2 and CO than any of the other conversion technologies examined. However, oil shale retorting (hydrocarbons and SO_2) and coal liquefaction and natural gas production (hydrocarbons) are likely to have difficulty in meeting Federal ambient short-term standards at the sites examined. On the other hand, coal gasification plants will probably have the least problem with air emissions. Finally, the urban developments created by the introduction of new energy facilities are estimated to cause higher peak ground-level concentrations of particulates, NO_2 and hydrocarbons than those produced by the facilities themselves - a result that is startling when one compares total emissions but plausible when the low height of the urban sources are taken into account. In any case, this problem would not necessarily affect development because present significant deterioration regulations ignore "non-point" sources such as urban development. Rewording of such regulations, which I should stress is not in consideration, could create a substantial roadblock to development.

The analysis indicates that the air pollution problems associated with large coal conversion facilities will be magnified considerably by any reclassification of substantial land areas to a "Class I" (strictest) PSD category. Such a ruling may sharply limit the maximum size of power plants and other facilities. The effect of such limitations could well be perverse, with declines in local air pollution and socioeconomic impacts being somewhat offset by problems associated with proliferation of transmission lines, roads and pipelines, inefficiencies of scale, greater region-wide habitat removal, etc. Examination of the tradeoffs among policies which directly or indirectly promote differing regional development patterns will have to be an important part of future work in the Western assessment.

Water - The idea that there is insufficient water in the West to provide for large scale energy development, especially if that development is to include mine-mouth conversion, is literally gospel in many quarters and has been a concern in this study as well as in several others (for instance, the Lake Powell Research Project, Reference 4). Although considerable attention was focused on accurately estimating the amount of water actually available to energy development, there is astonishing uncertainty both in terms of its physical availability (accounting for long-term trends) and legal availability. The morass of legal compacts, uncertain Indian and Federal water rights, and appropriations (and over-appropriations) as well as uncertainty about future agricultural expansion probably insures that a generally accepted estimate of water availability for energy cannot be arrived at in the next few years. It is probably safe to say, however, that availability is likely to be a problem in the Colorado River Basin, but will probably not be a major problem in the Upper Missouri River Basin as a whole (although demands on the Yellowstone River sub-basin probably will be a problem).

Getting a fix on the other side of the issue, that of water requirements for development, is a far more tractable problem. A detailed analysis of water needs (Reference 5) for those fuel cycles examined in the first phase indicated that substantial possibilities exist for reducing water use far below the figures generally cited by industry ....without incurring additional costs. Table 1 shows the water requirements for each conversion technology by site, assuming only that the plant designer wishes to minimize his total cost while reducing water consumption. Although one

TABLE 1. WATER REQUIREMENTS FOR EACH TECHNOLOGY BY SITE[a] (REFERENCE 5)

Site	Water Requirements[a] (1,000 acre-ft/yr)					
	Electric Power Generation	Lurgi	Synthane	Synthoil	TOSCO II	Slurry Pipeline
Kaiparowits/Escalante	29.82	NC	NC	NC	NC	NC
Navajo/Farmington	29.21	5.64	8.67	11.75	NC	NC
Rifle	28.47	NC	NC	NC	12.92	NC
Gillette	25.84	4.21	7.78	9.23	NC	19.17
Colstrip	26.66	4.62	7.81	10.30	NC	NC
Beulah	23.88	3.31	7.67	10.09	NC	NC

Acre-ft/yr = acre-feet per year
NC - not considered

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[a] For a 3,000 megawatt-electric power plant at 70-percent load factor, for 250 million cubic feet per day gasification facilities at 90-percent load factor, 100,000 barrels per day coal liquefaction and oil shale processing facilities at 90-percent load factor and a 25 million tons per year slurry pipeline at 100-percent load factor.

would assume that industry would use the same criteria, published estimates of water use (especially for the synthetic fuel facilities) have tended to be much higher than those shown.

Since most conversion plants are unlikely to return effluent streams to surface waters, much of the emphasis on water quality has focused on the effects of depletion and aquifer disruption rather than on the impacts of plant-generated pollutants. However, the residuals generated by all of the energy conversion facilities can represent a significant pollution problem over the long-term unless extreme care is taken in their disposal. Generally residual waste waters will be routed to onsite evaporation ponds. These ponds present two potential problems. First, leaching through the pond liner represents a potential threat to groundwater. Second, a pond failure - whether because of an event such as a flash flood or deterioration after facility shutdown - offers a potential threat to surface water. This problem is particularly significant because it tends to illustrate the one-dimensional nature of much pollution control legislation and regulations designed to deal with a single problem or environmental medium. Onsite ponding of residuals is the logical solution to the requirements of the Federal Water Pollution Control Act, which focuses on the protection of surface waters. However, this solution may trade a chronic problem - continual discharge of small quantities of residuals - for a future acute problem, or a surface water problem of possibly small magnitude for a potentially dangerous groundwater problem (since flushing of aquifers is usually a very slow process).

SECOND PHASE WORK

As noted above, the main thrust of work in the second phase of the Western assessment will be to conduct policy analysis - to identify and evaluate alternative policy measures and implementation programs that will enhance the benefits and minimize the adverse effects of future energy development.

Since the term "policy analysis" is one upon which many interpretations can be placed, I will "define" it in the context of the Western Assessment by very briefly describing its components as undertaken by the study team. First, the analysis will link the results of the impact assessment to the social, economic and political context within which development will take place, defining "how costs, risks and benefits will be distributed, which levels and specific agencies of government either have regulatory authority and responsibility and/or assistance programs, what laws, regulations, and policies are applicable, who the private participants are, and what interests and values are at stake (Reference 6)".

Second, the impact assessments will be subjected to sensitivity analysis, wherein critical variables identified in the initial assessment - such as pollution control efficiency, water use technology, stack height, etc. - will be altered to determine their effect on the severity and distribution of impacts. The purpose of this analysis is to identify those variables which are controllable by policy makers and which are critical determinants of impact.

Third, these key variables must be tied to policy alternatives which can control them. These alternatives include those available through the present "policy system" as well as those which require institutional, social or legal changes in the system.

Fourth, the first kind of evaluative assessment must be repeated with this expanded list of policy alternatives, and the consequences of the alternatives - their costs, risks and benefits, their implementation problems, and the distribution of the impacts -

are assessed. This assessment of policy alternatives represents the major product of the study.

Since the potential scope of the Western Assessment is practically boundless and resources are limited, the policy analysis described above will focus on five substantive areas:

- o Water Availability and Quality
- o Air Quality
- o Planning and Growth Management
- o Facility Siting
- o Interregional and National Economics

Further descriptions of the expected analysis in each area are available in the second Work Plan (Reference 6).

A small but significant effort will also go into cleaning up some "loose ends" from the first phase's impact assessment. For instance, the regional analyses will be redone using scaled down....and more realistic....levels of development, and additional technologies will be included in the site - specific analyses, including enhanced oil recovery, in-situ oil shale, and geothermal development.

PRODUCTS

The Western assessment has already produced a number of reports and will, of course, produce more in the future. The assessment's first product was a First Year Work Plan (Reference 7) a comprehensive plan-of-attack for the study that has proven useful both to those interested in the study as well as those interested in pursuing similar large-scale assessments. The assessment's phase I report, Energy From the West (Reference 1) presents the results of the impact analysis phase as well as of the preliminary policy analysis already completed. Two technical reports on water requirements for fossil development (Reference 5) and transportation costs (Reference 8) have been produced. Future reports will include, besides a final technology assessment report:

- o a number of technical reports on various topics, including a volume describing the energy technologies and their policy systems
- o a Research Adequacy report describing research topics critical to understanding Western energy development which are not being appropriately addressed
- o a report describing the impact analyses completed by the assessment
- o a series of summary reports, addressed to different categories of policymakers, identifying and assessing policy alternatives for enhancing the benefits from and mitigating the adverse impacts of energy development in the West

Although a very considerable amount of time and effort has gone into preparing the reports thus far, and we expect to channel an equivalent or greater amount into producing the remaining reports, we also recognize that the benefits of a complex study of this nature are rarely reaped by writing a terrific report that everybody then reads. Instead, the groundwork for the eventual success of a policy-informing research project is laid early in the process of conducting the study by involving the eventual users in the process, getting them to feel that they have a stake in the product, and maintaining a relatively surprise-free environment. The Western assessment has maintained a commitment to this philosophy via:

- o extensive dissemination of reports in early draft through final form
- o maintenance of an Advisory Committee consisting of representatives of Western communities, developers, Federal government, environmental groups, etc.
- o continuing and extensive contacts with state and local agencies, etc.
- o conduct of extensive series of briefings and interviews with State legislatures, governors' staff, Senate/Congressional staff, and other potential users
- o attendence and presentation of papers at academic and other forums (such as AAAS meeting, etc).

In most studies, the process of interacting with the "user community" either ends or is sharply curtailed upon publication of the final report, because of funding cutoff and disbandment of the project team. Unfortunately, this is precisely the moment when the interactive process becomes most critical, when new audiences and new critics gain access to the study results. It is also a time when, with formal contractual commitments complied with, the project team is available as a formidable tool for conducting short term policy analysis. In recognition of this, EPA is considering moderate funding of the University of Oklahoma team beyond the formal study period. This funding will allow the team to respond to requests by interested parties for briefings, to answer criticisms, and to respond to EPA's or others' requirements for analysis of legislation and other policy-oriented work. This "follow-on" period is expected to last at least six months.

CONCLUSIONS

Results of the impact analyses conducted by the Western assessment show that the impacts of large scale energy development exhibit strong variations in kind and magnitude depending upon location and technology. It may thus be possible to reduce the adverse impacts of development by tailoring site/technology combinations (for instance by placing only low-water-use technologies such as Lurgi gasification in water-short areas) as well as by restricting development in especially vulnerable areas. The feasibility of such a program is enhanced by the fact that, at least for the next few decades, Western coal reserves far outweigh the coal requirements. This provides at least a theoretical abundance of potential sites for near term development. Although this situation may be relatively short-lived, the time "window" may be large enough to allow for the development of superior mining and conversion technologies, economic assistance programs, etc. before locational flexibility disappears with shrinking reserves and growing demand.

However, the size of the "window" is clearly dependent upon Federal, State and local constraints on development. The more land removed from the development market, the less flexibility is available to both industry and government for selecting only the most desirable sites. Although development constraints are a critical part of a rational development process, it is not clear that prohibitions or restrictions on mining and conversion are being established in any coordinated, comprehensive, multi-media way. Prohibitions based on impacts in a single medium (air, land, water) or impact area (social, economic, etc.) must be weighed against the possibility of excluding from development land which may be judged desirable when total adverse impacts are taken into account.

Locational flexibility should be viewed as a positive value, and policies designed to enhance this flexibility should be formulated and pursued. For instance, any argument that sufficient coal leases have been granted to provide for satisfying demand, thus negating any requirement for further leasing, must be judged in the context of this flexibility. If the lands already under the lease are not those that are most socially, economically and environmentally desirable to develop, then the government should consider programs to carefully increase leased area, or to "trade" vulnerable land under lease for less fragile unleased property. Similarly, governments should not refuse rights of way for new transportation facilities because sufficient capacity exists to satisfy foreseeable demand, until the issue of the desirability of the resources made available by new facilities is factored into the decision making process.

The analysis has tended to confirm much that is "common knowledge" in the West, for instance, the difficulties facing small towns and the air pollution problems associated with large power plants. That many of these problems continue to be dealt with inadequately is indicative of shortcomings in past research as well as in the energy policy system itself. Many past research programs have been less than fully successful because they failed to translate problem definitions into information that was relevant to policymakers' interests and constituencies, and problem solutions into programs that were able to be implemented. This research program will also fall short of its goals if it cannot learn from this. However, the translation process is made extremely difficult because of shortcomings in the policy system, including overlapping responsibilities, lack of multi-media perspective, artifical geographical boundaries, etc. The single greatest challenge for the Western assessment in its second phase of research will be to devise ways to either accommodate the policy system's shortcomings while achieving environmental and socioeconomic goals, or else to change the system in a politically acceptable manner.

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OHIO RIVER BASIN ENERGY STUDY

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INTRODUCTION

The Environmental Protection Agency (EPA) has responded to a Congressional mandate to conduct "an assessment of the potential environmental, social, and economic impacts of the proposed concentration of power plants in the lower Ohio River Basin. The study should be comprehensive in scope, investigating the impacts from air, water, and solid residues on the natural environment and residents of the region."[1]

Citizen Concern

This directive represents a significant achievement for a community of environmentally aware citizens who, in the early 1970s, became concerned with accelerating plans for power plant development along the main stem of the Ohio River between Portsmouth, Ohio and Louisville, Kentucky. Currently, nine power plant projects are either under construction or in an active planning phase along this 250-mile river reach (see Figure 1). In excess of 12,000 megawatts of generating capacity, mostly coal-fired boilers, would be built if announced construction plans were all implemented.

Two factors which intensified citizen concern over this development were quite apparent. The first results from the relatively lax environmental controls that apply to existing plants, for example, the Clifty Creek plant just downriver from Madison, Indiana. This coal-fired plant owned by the Ohio Valley Electric Corporation (OVEC), a consortium of fifteen investor-owned utilities in Indiana, Ohio and Kentucky, operates in a base-load mode to

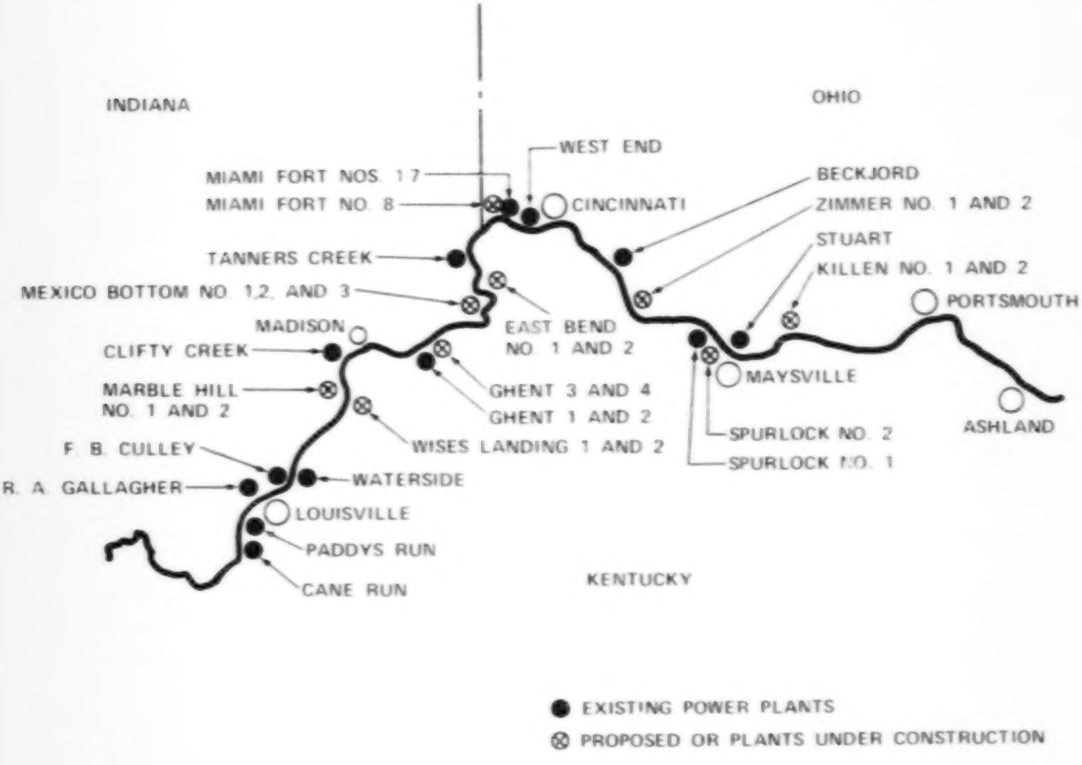
INDIANA
OHIO
KENTUCKY
WEST END
MIAMI FORT NOS. 1-7
MIAMI FORT NO. 8
CINCINNATI
BECKJORD
ZIMMER NO. 1 AND 2
STUART
KILLEN NO. 1 AND 2
PORTSMOUTH
TANNERS CREEK
MEXICO BOTTOM NO. 1,2, AND 3
EAST BEND NO. 1 AND 2
MADISON
CLIFTY CREEK
MARBLE HILL NO. 1 AND 2
GHENT 3 AND 4
GHENT 1 AND 2
WISES LANDING 1 AND 2
MAYSVILLE
SPURLOCK NO. 2
SPURLOCK NO. 1
ASHLAND
F. B. CULLEY
R. A. GALLAGHER
WATERSIDE
LOUISVILLE
PADDYS RUN
CANE RUN
● EXISTING POWER PLANTS
⊗ PROPOSED OR PLANTS UNDER CONSTRUCTION

Figure 1. Power plants along the Ohio River: Existing and Planned.

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*A substantial portion of the downtown section of Madison is listed in the National Register of Historic Landmarks.

supply electrical energy to the ERDA-owned uranium enrichment facility at Portsmouth, Ohio. Clifty Creek, with a nameplate capacity of 1,304 megawatts, was built in the mid-1950s with cyclone separators and crude electrostatic precipitators for particulate control.[2] The plant, with three stacks and their dense plume of particulates, sulfur oxides and nitrogen oxides, is an intrusion over much of the adjacent landscape, including Indiana's idyllic Clifty Falls State Park, situated above it on high bluffs. Residents in the nearby historic* town of Madison, Indiana, complain of the eyesore, as well as question the effects that its pervasive, prolific emissions have on their health and welfare.[3]

The second factor raising citizen concern is the nationwide debate over the intrinsic safety of nuclear power reactors and their supporting fuel cycles. This national debate has been brought into a regional focus by Public Service of Indiana's (PSI) plans to build a 2,260 MWe reactor complex at their Marble Hill site, a dozen river miles downstream from Madison.[4] In 1974, the announcement of these plans triggered strenuous reaction in Save-The-Valley (STV), a citizens' organization incorporated that year in Kentucky and now operating in three states. STV questions the need for much of the current power development activity within the region and opposes most of the specific projects under development.

The PSI Marble Hill project has received an especially large amount of STV attention as the first nuclear units planned to be built in Southern Indiana.[5] Prior to the initiation of the regional study described in this paper, STV and other environmental groups called for a moratorium on all new power plant planning, permitting and construction activities for at least a three-year time period, until a comprehensive study could be completed.[6] Meanwhile, PSI states that initiating its Marble Hill project now is important if power shortages in the mid-1980s are to be avoided. It was in this context that Congress requested a regional study on power plant development.

The study, later designated the Ohio River Basin Energy Study (ORBES), was assigned to the Integrated Assessment Program, a component of the Energy/Environment Interagency R&D Program[8] managed by EPA's Office of Energy, Minerals, and Industry. A work plan for ORBES was prepared[9] which cast the study in the general form of a technology assessment.[10] Several unique features were incorporated into this work plan in order to accomodate the special requirements of this study. These included the use of three simultaneous preliminary assessment teams located on seven separate campuses within the four-state area, and the use of an "Experimental Management Plan"[11] to provide day-to-day management capability over the entire Phase I effort.

Study Structure

The organizational structure of ORBES Phase I is depicted in Figure 2.[12] Regional Technology

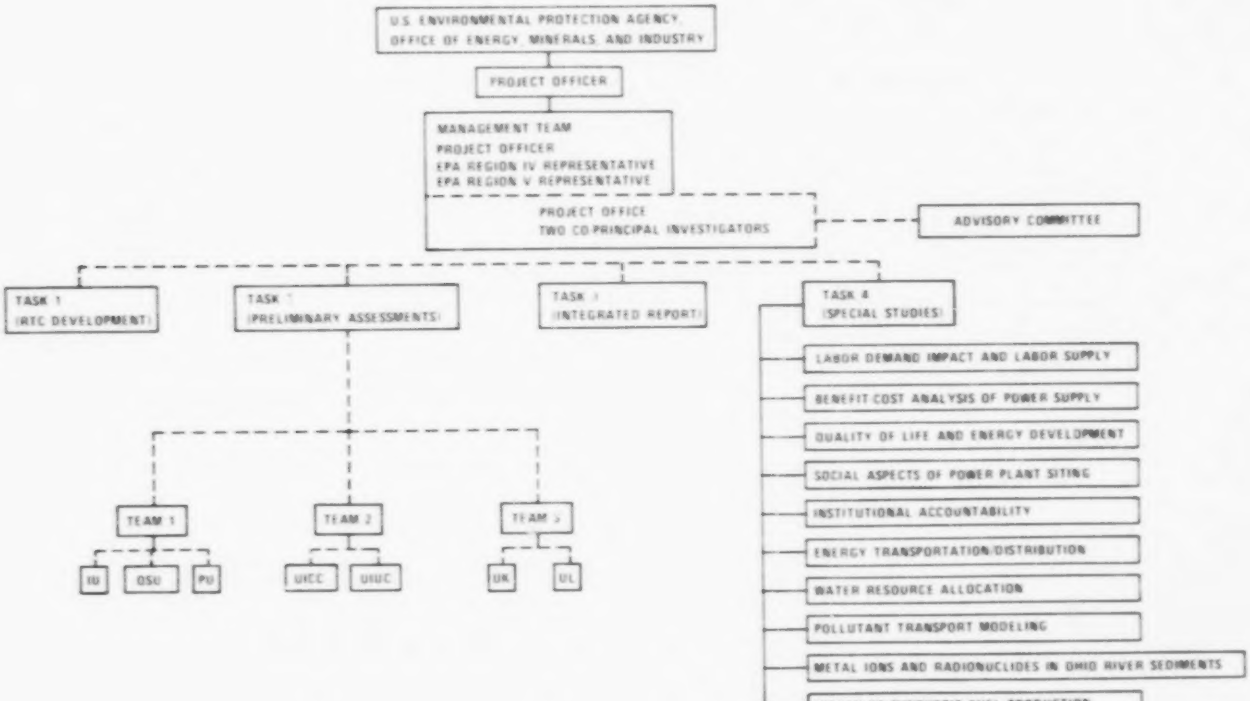
U.S. ENVIRONMENTAL PROTECTION AGENCY,
OFFICE OF ENERGY, MINERALS, AND INDUSTRY
PROJECT OFFICER
MANAGEMENT TEAM
PROJECT OFFICER
EPA REGION IV REPRESENTATIVE
EPA REGION V REPRESENTATIVE
PROJECT OFFICE
TWO CO-PRINCIPAL INVESTIGATORS
ADVISORY COMMITTEE
TASK 1
(RTC DEVELOPMENT)
TASK 2
(PRELIMINARY ASSESSMENTS)
TASK 3
(INTEGRATED REPORT)
TASK 4
(SPECIAL STUDIES)
TEAM 1
TEAM 2
TEAM 3
IU
OSU
PU
UICC
UIUC
UK
UL
LABOR DEMAND IMPACT AND LABOR SUPPLY
BENEFIT-COST ANALYSIS OF POWER SUPPLY
QUALITY OF LIFE AND ENERGY DEVELOPMENT
SOCIAL ASPECTS OF POWER PLANT SITING
INSTITUTIONAL ACCOUNTABILITY
ENERGY TRANSPORTATION/DISTRIBUTION
WATER RESOURCE ALLOCATION
POLLUTANT TRANSPORT MODELING
METAL IONS AND RADIONUCLIDES IN OHIO RIVER SEDIMENTS
IMPACT OF SYNTHETIC FUEL PRODUCTION

Figure 2. ORBES Phase I structure.

Configurations (RTCs) in the form of comprehensive scenarios were developed for the four-state ORBES region (see Figure 3). The preparation of these RTCs was the responsibility of the Task I team, composed of selected research specialists for the Special Studies (Task 4) group and of the leaders of the three Preliminary Assessment teams (Task 2). The Task I report[13] describes the approach used to build the electrical energy demand and the technological supply components of the four RTCs that were developed. The three Preliminary Assessment teams were composed of researchers from: (1) Indiana University, Purdue University and The Ohio State University, under the leadership of Professor Robert Bailey; (2) University of Kentucky and University of Louisville, under the leadership of Professor Hugh Spencer; (3) University of Illinois at Urbana and University of Illinois at Chicago Circle, under the leadership of Professor Ross Martin.

Several areas of particular interest, which required more detailed exploration than was possible in the Task 2 framework, were each assigned a Special Study (Task 4). Some special study results were available to the Task 2 teams, but the majority of these results will receive more extensive application in the Phase II analysis. These several research products are being analyzed and will form the primary basis for the preparation of an integrated report (Task 3) which will be delivered to Congress and be made available for public distribution this fall.

The project officer was ably assisted in monitoring the direction of this research by EPA colleagues from the Chicago and Atlanta EPA regional offices. These offices are responsible for EPA activities within the ORBES region north and south of the Ohio River, respectively. Most importantly, the co-principle investigators of the Experimental Management Plan, Professors James Stukel and Boyd Keenan, effectively operated the ORBES Project Office, and undertook the many coordination and representation activities associated with that function, thereby ensuring a successful completion to ORBES Phase I.

Finally, the accountability question associated with most technology assessments assumed major importance for the ORBES work. Both its genesis and prevailing community attitudes dictated the need for ORBES to give particular attention to the several divergent mind sets toward power development that characterize the various interest groups in the study. In order to accommodate this need, while also complying with the strict time schedule of Phase I, an Interim Steering Committee was formed shortly after the issuance of the funding grants to the universities. This group and its successor, the ORBES Advisory Committee, were invited to participate in all phases of the first three tasks. This evolving committee is composed of representatives of federal agencies, state administrative and legislative branches, local utility firms, the coal extractive industry, labor, agriculture, and the general public.[14] In addition, communication

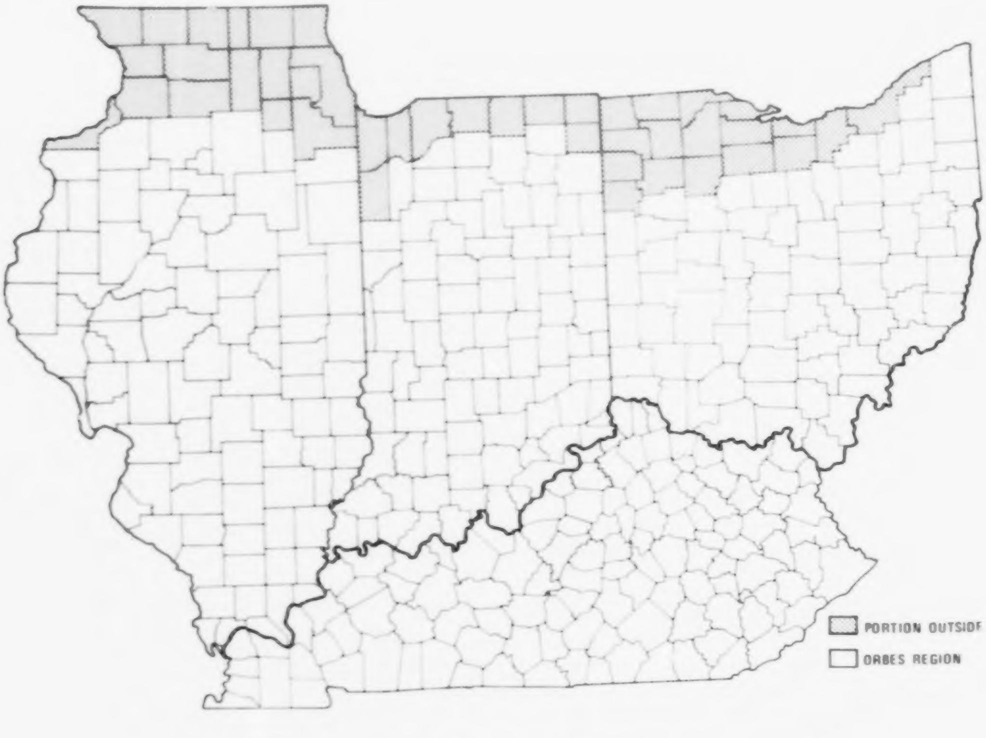

Figure 3. Ohio River Basin energy study region (Phase I)

between ORBES researchers and the interested public has been aided by a monthly newsletter, distributed to nearly three thousand recipients, and a series of bimonthly progress reports by all three Preliminary Assessment Teams, presented at public meetings throughout the ORBES region. A great deal was learned in these efforts about what is required of academic researchers to effectively communicate with various segments of the public about public policy issues, yet additional efforts are needed to increase the effectiveness of these communications as the study progresses.

DESCRIPTION OF THE ORBES PROJECT

The methodology utilized in ORBES relies on the construction of possible future economic activity and energy demand states for the region through the year 2000. There was no attempt to predict in Phase I what the actual future state of energy demand and economic activity might be, but rather to select a number of possible states for analysis and an intercomparison of their regional and local implications for the region's residents. These hypothetical states were constructed by selecting national energy forecasts produced by other studies and disaggregating these to the ORBES region.

Regional Technology Configuration

Two levels of growth rate for electrical energy demand were chosen. One, a moderately high growth rate, was adapted from Dupree's Bureau of Mines study, "U.S. Energy Through the Year 2000";[15] the other was constructed from the Technical Fix Scenario of the Ford Foundation's Energy Policy Project[16] The former, designated BOM, projects an annual growth rate in electrical energy demand of 5.8%, while the latter, designated FTF (Ford Technical Fix), projects an average annual growth rate of 2.8%. Although these growth rates do not represent the extremes of what was considered at the time possible to sustain over the remainder of the century, they do reflect quite different schools of thought concerning what is possible and necessary to maintain economic and social viability within the region. The economic, demographic, and technological changes which are explicit in these scenarios are summarized in the Task 2 assessment reports[17,18,19] and in the original sources.[20,21] The specific adaptation of these national scenarios to the ORBES region is described in a supplementary ORBES report.[22]

These varying demand growth scenarios were overlaid by differing mixes of technological options postulated for new generating plants to come on-line after 1985. All plants whose sites and technological types were announced by their utility owners on Federal Power Commission Form 67 were incorporated into the ORBES RTCs.[23] It was necessary for the FTF RTCs to delay the completion of announced plants in order to accomodate the utilities' announced plans to a lower growth rate.[24] For the BOM RTCs, two mixes of coal-fired and nuclear-generating plants were utilized, one 50% of each, the other 80% coal/20% nuclear. For the FTF RTCs, few plants beyond those already announced were required. These were alternately chosen to be all nuclear or all coal-fired.

These postulated new power plants were sited, that is, hypothetical locations selected, on a county level according to a number of engineering and locational requirements. Thus, a separate list of counties, each with one or more power plants of specified size and technological type to be operating by a specified year between 1975 and 2000, was constructed for each of the four RTCs selected.[25] These lists, along with the background sociological and economic conditions and assumed coal supply sources, composed the four RTCs analyzed by the three Task 2 Assessment Teams.

Assessment Studies

The Task 2 Assessment Teams functioned quasi-independently throughout their seven months of operation. They had complete freedom to choose and utilize their own assessment approaches and methodologies. While a moderate effort was made to develop a joint data base with which to describe the existing natural and developed status of the region, the use to which this data base was put was left to the discretion of the individual assessment teams. This approach offers a high validity for the findings and conclusions independently arrived at by two or more of the teams. Moreover, it will give a marked enrichment to the project's results, as more opportunity to consider perspectives that are unique to one or two states is provided.

The ten special studies[26-35] funded within Task 4 are too numerous and detailed to describe here. Each is available as a separate report from their individual authors. One of these[29] is the first published attempt to operationalize a new paradigm for social-environmental analysis developed by Erik Cohen.[36] Others involved sophisticated computer studies of energy transportation costs[31] and skilled labor demand and availability,[26] while another provided a detailed analysis of the legal and institutional framework which guides energy development decision-making within the region.[30]

SELECTED PRELIMINARY RESULTS

ORBES Phase I produced a rich array of findings with respect to the possible future effects of energy development in the region. In a few cases there are differences in the conclusions drawn by different researchers or research teams. These differences require additional close analysis to elucidate the influence differing input assumptions or analysis techniques had in producing them. Other results require further validation as research approaches are refined. But a number of generalized conclusions can be stated with a high degree of confidence as Phase II is nearing completion. A selection of these are outlined in the following sections.

Effects on Natural Resources

The ORBES region is fortunate to have an abundance of natural resources. Depending upon location within the basin, surface resources range from richly productive agricultural soils to hardwood forests of outstanding pastoral charm. Thirty percent of the nation's bituminous coal resources underlie the western portion of the region. This coal contains more chemical energy than is contained in all the discovered petroleum reserves in Saudi Arabia. As this coal is high in sulfur content, it requires moderately expensive sulfur control devices when burned in utility boilers in order to prevent overloading the atmosphere with sulfur dioxide and its oxidation products. The extensive Appalachian coal province lies within and borders the region on the east. Deposits within eastern Kentucky and southern West Virginia contain some of the nation's highest quality coal reserves, substantial blocks of which are held for metalurgical production.

Extracting this coal for utility use produces a wide range of impacts upon existing surface conditions and uses of the land. This damage, which varies widely in degree and scope, can, in principle, be prevented or mitigated so as to prevent serious permanent impairment in land productivity, if sufficient care is exercised before, during and after the extraction activity. Underground mining, with its potential problems of delayed but long-term susceptability to subsidence, coal refuse piles and acid mine drainage, would affect more land area than would surface mining during the next two decades. Under the BOM RTCs, about half as much land would be committed to siting new conversion facilities as to coal extraction, while for the FTF RTCs, this ratio would drop to about one-fourth. Furthermore, only about half as much land area would be affected by extraction activities under the FTF as under the BOM RTCs.

New requirements for transmission line corridors would be approximately half of the FTF and equal to the BOM RTCs' land-use requirements for coal mining activities. These corridors are capable of multipurpose use, although there would be some impairment of value for other uses. The magnitude of effects expected from waste disposal from coal burning and nuclear fissioning is difficult to estimate, since the technologies which produce and deal with these wastes are in a rapid state of flux, as are the regulations that control these activities. Imprudent choices with respect to the implementation and control of technological alternatives could create severe long-term hardships on affected localities within the region.

Possibly of equal importance in terms of severity and extent of these enumerated changes in land use due to energy development would be the resulting land-use changes as this energy was utilized to build, operate and maintain new homes, shops, factories and transportation facilities throughout the region. Again, current and future decisions regarding the intensity and patterns of land-use conversions to be made during the next two decades will strongly affect the state of the region in the year 2000.

Increasing conflict between energy and agricultural interests is inevitable. Public policy decisions will have to be made with respect

- o regional vs. local controls over areas of more than local significance;
- o developing priorities for choosing among alternative use activities;
- o government involvement in encouraging new industrial, commercial or residential development of energy-impacted lands rather than of prime agricultural or pastoral lands;
- o public land-use planning vs. market mechanisms to make land-use determinations;

Water withdrawal requirements within the ORBES region for the high-growth-rate scenarios would begin to significantly reduce tributary stream flows during periods of low-flow. The principal water consumption requirements come from the cooling needs of power plant condensers. The current best practice is to use closed cycle cooling, a process which relies on evaporative cooling from either cooling towers or cooling ponds. The analysis which produced the above result ignores any future requirement for agricultural irrigation, yet consumptive water use for irrigation may increase substantially during any sustained future drought condition.

Equally important is the observation that a significant amount of water flowing down the Ohio River originates as rainfall outside the four-state region. Thus, if large future increases in water consumption in the upstream states of Pennsylvania and West Virginia were to occur, this surplus water would no longer be available for downstream uses during periods of low-flow in the ORBES region. Tracing this impact further downstream, navigation on the Mississippi River could be significantly constrained below its confluence with the Ohio at Cairo under these conditions.

Effects on Developed Resources

Few constraints on energy development due to the lack of or its effect upon developed resources were found. High rates of growth for coal utilization would require a rebuilding of rail lines throughout the region to allow the movement of unit trains; however, there would be no lack of workers or material to accomplish this task.

Under the BOM RTCs a significant shift in the utilities' share of regional and national capital markets would have to occur. It is not clear whether this shift would lead to an economically stable condition, or whether other necessary segments of the fuel cycle, such as coal extraction and transportation, would be able to compete successfully in the same capital markets with utilities. Failure to do so would create coal shortages, even at escalated prices.

Construction labor requirements under the BOM RTCs are sufficiently high in some specialized skills, such as boiler makers and pipefitters, that workers indigenous to the region are not likely to be found in sufficient numbers to meet the projected demand. Under the 80% coal BOM RTC, the number of new miners and related workers would have to expand by more than seventy percent by the end of the century in order to produce the required coal. Such an increase would dramatically reverse historic trends of population migration from coal production areas. Labor supply for the FTF RTCs should be readily available within the region, with moderate levels of recruitment and training.

Effects on Environmental Media

Water quality need not be impacted, even under the BOM RTCs. Technology is available to control discharges from all point sources, such as cooling water blowdown, if there is a will to enforce existing standards and to implement proposed future standards. Control techniques for surface erosion and deep mine drainage must rely on prevention through careful planning, rather than on dedicating perpetual treatment facilities. At low-flow, water quality in water-short tributaries may be degraded from existing levels because of the reduced dilution factors that would result from increased consumptive uses. Existing industrial and municipal dischargers would have to improve the quality of their discharge effluent in order to compensate for this effect in water quality-limited stream reaches. The extent to which this mitigation measure would have to be employed is subject to further analysis.

Waste disposal, particularly ash and scrubber sludges, must be carefully engineered. These materials contain the bulk of heavy metals and other trace elements which naturally occur in coal deposits, including several long-lived radionuclides. These materials should be disposed of in such a way that they and their leachates are permanently isolated from ground and surface waters. Existing regulations may not be adequate to promote or guarantee the attainment of this objective.

The most significant adverse media effect would be that predicted on air quality. The siting patterns developed in ORBES and other studies predict that most power plants would be sited along the main stem of the Ohio and of its principal tributaries.[37] These lines of preferred power plant sites are co-directional with the preferred movements of air masses under persistent wind conditions.[38] Under these conditions, power plant emissions are diluted with previously emitted upwind power plant emissions, thus producing a cascading effect on ambient pollutant concentrations. Modeling of the combined emissions from these line sources under worst case conditions indicates that a violation of the primary sulfur dioxide 24-hour ambient standard would likely occur under the BOM 80% coal RTC. This violation would occur if only the new plants to be operational after 1985 were operating. Because the procedures currently being utilized by the EPA regions in reviewing new source applications are not designed to capture this "corridor" effect, a review of these procedures is in order, particularly for the determination of allowable increments under the Prevention of Significant Deterioration of Air Quality (PSD) requirements. Also indicated is the need to evaluate this effect for regulatory efforts under EPA's air quality maintenance program whose goal is to assure that areas presently meeting ambient standards will do so in the future.

Communities which allocate this allowable PSD increment in air quality degradation to a new power plant may not be able to absorb any increase in economic activity from other PSD controlled point sources. The equity in this situation becomes clouded as a number of new upwind power plants through their combined emissions, are allowed *de facto* to capture all or a majority of the allowable increment for a downwind community. Alternate procedural approaches to allowing this capturing of pollution rights are to require more stringent emission controls, or to follow EPA's present policy which is to not take full account of this cascade or corridor effect. The result of continuing to follow the latter alternative would be an increasing greying of the region's air.

This situation becomes even more serious when viewed in the perspective of atmospheric transformation of sulfur dioxide into acid sulfate aerosols. These aerosols cause more respiratory disorders than either sulfur dioxide or particulates do independently. Conservative rates for this conversion process in plumes released into typical Ohio Basin ambient air are sufficiently high that more suspended particulate mass is produced by this secondary process than is directly emitted in the form of fly ash from a well-controlled plant. The sulfate aerosol has a smaller average particle size than primary particulate emissions. As a result, it stays suspended in the atmosphere longer and therefore travels farther; it is more readily trapped in the human lung where it produces acute and chronic effects; and it is more effective in reducing visibility by creating atmospheric haze or turbidity. Sulfate aerosols and nitrate aerosols are the principal acid-forming agents in acid precipitation, which has increased substantially in the northeast over the past fifteen years. Power plant nitrogen oxide emissions are implicated in the formation of the nitrate aerosols that are associated with acid rain. Although there is much to learn concerning the role of power plant sulfur and nitrogen oxide emissions in the formation of undesirable secondary pollutants, and even more to learn about the several possible effects these secondary pollutants have on human health, material corrosion and weathering, ecosystems' atmospheric turbidity, agricultural production, forest growth and geologic erosion, inferences from what is presently known suggest that significant adverse effects are currently being experienced from coal-fired power plant operation in the ORBES area and other adjacent regions. The findings of ongoing research sponsored by EPA, ERDA, EPRI, NSF and other funding sources should further our understanding of these problems over the next several years.

Socioeconomic Effects

It was not possible during the first year of ORBES to determine adequately what public and occupational health effects might be experienced under each RTC. Large uncertainties arise in areas such as what the effect of currently required control measures for coal mine dust will have on the incidence of black lung disease cases, or what the full effect of acid sulfate aerosols have on the incidence or aggravation of human respiratory and circulatory diseases. A substantial research effort is required to remove these uncertainties, but further efforts will be expended in the next year of ORBES to apply our limited knowledge to bracketing the range of these several effects. Policy options to deal with such uncertainties need to be refined, and the effects of their implementation in the ORBES region require evaluation.

Some effort has been given to evaluating possible local community reactions towards energy development. There exist significant divergences in individuals' perceptions about the local affects of energy development. These differences in perception about what a community would experience must be overlaid with analyses of what basic community attitudinal orientations towards change may exist, and of what the current and recent historical socioeconomic community needs are, in order to predict community reactions confidently. Only the attitudinal orientation study based on Cohen's paradigm has been attempted. Inovative approaches must be developed in order to forecast local and regional community reactions to energy development with reasonable certainty.

Regional economic activity by industrial sector has been projected by the EPA Technology Assessment Modeling Project (TAMP) for the ORBES region to the year 2000.[39] These projections have yet to be integrated with the other ORBES analyses. They form the basis for predicting future air and water pollutant release rates and for analyzing secondary effects of constructing and operating energy conversion facilities. Because of its detailed description of emissions from industrial sectors, TAMP is a valuable tool for these purposes.

Most counties within the ORBES region which possessed the engineering-related requirements for new power plant development were judged not to be susceptible to boom-town effects from power plant construction. Relatively convenient access to urban centers would allow construction workers to commute to construction sites rather than overcrowding local communities which may have inadequate housing, schools, stores, entertainment, sewage treatment, fire and police protection and roads. For the few counties whose isolation from urban centers may be sufficient to create a local boom-town condition, the hardships created for residents may be severe. Rising prices and taxes added to local overcrowding would produce extreme dissatisfaction among the resident population, especially among those who depend upon fixed incomes.

CONCLUSION

The ORBES project to date has primarily been an issue-raising activity, an effort to broadly scope out the possible questions and problems related to an accelerating rate of power plant development in the Ohio River basin. Principal among these problem areas identified to date is that of air quality degredation. Water availability for all projected and anticipated uses may become a problem in the future. Coal extraction activities could degrade land quality and productivity for local areas, or produce other land-use conflicts, especially with agriculture in Illinois. Certain coal mining practices could, if uncontrolled, continue to create water quality problems for decades to come. Some local discomfort from a rapid expansion of construction activities may be experienced in communities remote from experienced labor pools.

All of these identified problems can be reduced significantly or even eliminated. However, most of the solutions appear to depend upon a level of regional coordination which does not presently exist. In this multi-state region in which the desire for home rule is strong, development trends have been identified which transcend the powers of any locality, any county or any state to cope with adequately. The many layers of planning, review and control now operating in the region do not individually possess sufficient authority or control adequate resources to ensure that the public good will be served and protected.

Ironically, the interest groups who are the most active in their attempts to protect existing resource values and life styles are also most distrustful of higher levels of governments' ability to protect the values they cherish. Yet, only through developing and implementing a regional strategy for guiding energy development can their values be protected. The possible mechanisms through which to accomplish this objective while simultaneously meeting other local and regional needs deserve thoughtful attention by all affected parties.

Finally, the desire for and pursuit of the good life on the part of many residents in the region is in part responsible for creating the current power plant development activity. It is this same activity which has stimulated many citizens' concerns about how permanent their good life is likely to be. Understanding the dynamics which create these paradoxes is a necessary step in bringing about their resolution. ORBES' goal is to increase that understanding among all affected parties.

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ELECTRIC UTILITY ENERGY SYSTEMS INTEGRATED TECHNOLOGY ASSESSMENT

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Washington, D.C.

INTRODUCTION

Electricity has become a vital component of twentieth century American life. No other energy form in our industrialized society has achieved such a multiplicity of uses. No other energy form is as convenient to convert into mechnical motion, light or heat at its point of end use. Electronic communications and information processing are wholly dependent upon a reliable flow of electrical energy. Industrialized society as we know it cannot function without copious quantities of this vital form of energy. Yet the supply of this essential commodity is bought at a price. This price is not only paid in monetary terms, but frequently is paid for in increased asthma, turbid skies, dammed rivers, acid rain, and other myriad side effects of electricity production.

Much attention has been given in the last ten years to these and other problems related to electricity production and distribution. Many environmental effects which result from the operation of the electric utility industry have been identified. Nonetheless, EPA's Office of Energy, Minerals and Industry (OEMI) recognized that comparatively little was understood about the utility industry and its support industries as an integrated system, a system which now pervades nearly every niche of our manmade and natural environments. In order to provide a clearer understanding for those whose responsibility it is to maintain, and in some cases, to restore the environmental quality affected by utility operations, OEMI initiated a comprehensive study of the electric utility system.[1]

A contract to perform this research effort, entitled "An Integrated Technology Assessment of Electric Utility Energy Systems (ITA), was awarded June 30, 1975, to the Teknekron firm in Berkely, California.[2] It was funded as an element of the Integrated Assessment Program[3] which is a component of the Energy/Environment Interagency R&D Program.[4] The ITA as originally conceived was to require three years to complete. It was to be a comprehensive study on a national and regional level of the air, water and solid waste pollutants associated with all aspects of electricity production and of how these pollutants affect human health and welfare and natural ecosystems.

The ITA had two primary goals.[5] The first was to provide EPA with the capability to assess the environmental, economic, institutional and social effects of the generation of electricity and of those activities which supply the fuels used to produce electricity. The second goal was to assist EPA in developing research and development programs whose results are necessary to control the excessive adverse side-effects of electricity production and to more accurately determine the extent and intensity of those effects. The time frame for the assessment is the period 1975-2000.

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Three policy issues were selected to guide the development of analytical capability during the initial phase of the ITA:

- What interim sulfate strategy should EPA adopt? The strategy should focus on controlling emissions of sulfur dioxide and of other possible precursors and catalysts contributing to sulfate formation. Where uncertainty exists on each factor's full contribution, the strategy must incorporate an acceptable level of risk aversion and take into account the current state of knowledge about sulfate formation, transport and effects.
- What strategy should EPA adopt in response to the continuing curtailments of natural gas supplies to electric generating plants?
- How appropriate is EPA's "significant risk" criterion for judging the acceptability of converting gas or oil-fired plants to coal?

The first of these issues was given primary attention, although the three are tightly interrelated. Each emphasizes atmospheric rather than aquatic emissions. Another dominant feature of all three issues is their recognition of a trend towards increased reliance upon coal-fired fossil fuel plants in the near term.

Early in the assessment process it was decided that the complex nature of electric utility energy systems required a descriptive model that would reflect their behavior under a variety of external influences. Such a model, the Impact Assessment Model (IAM), has been developed and exercised in the first phase of the ITA. This paper describes the principal features of the IAM, atmospheric transport analysis and selected assessment results. The IAM simulates pollution releases associated with electrical generation and the economic impacts of alternative policies for pollution control on the utility industry and electricity consumers. The atmospheric transport analysis focuses on regional atmospheric transport processes which, under adverse meteorological conditions, can significantly impact air quality hundreds of kilometers from the area of emission releases.

ITA DESCRIPTION

The underlying conceptual framework for the ITA is shown in Figure 1. It embodies four key elements:

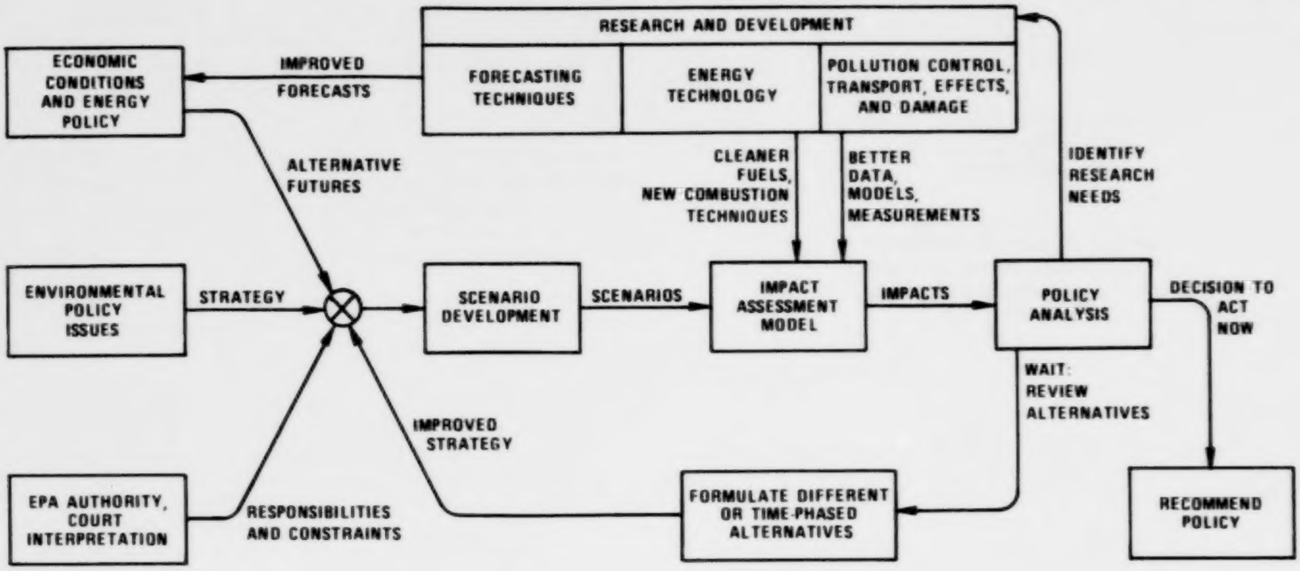
RESEARCH AND DEVELOPMENT
FORECASTING TECHNIQUES
ENERGY TECHNOLOGY
POLLUTION CONTROL, TRANSPORT, EFFECTS, AND DAMAGE
ECONOMIC CONDITIONS AND ENERGY POLICY
IMPROVED FORECASTS
ALTERNATIVE FUTURES
CLEANER FUELS, NEW COMBUSTION TECHNIQUES
BETTER DATA, MODELS, MEASUREMENTS
IDENTIFY RESEARCH NEEDS
ENVIRONMENTAL POLICY ISSUES
STRATEGY
SCENARIO DEVELOPMENT
SCENARIOS
IMPACT ASSESSMENT MODEL
IMPACTS
POLICY ANALYSIS
DECISION TO ACT NOW
WAIT: REVIEW ALTERNATIVES
IMPROVED STRATEGY
EPA AUTHORITY, COURT INTERPRETATION
RESPONSIBILITIES AND CONSTRAINTS
FORMULATE DIFFERENT OR TIME-PHASED ALTERNATIVES
RECOMMEND POLICY

Figure 1. Conceptual framework for the electric utility ITA

- Selection of policy issues and development of scenarios that illustrate alternative EPA strategies for addressing the issues;
- Use of models, data bases and analytical techniques to estimate each scenario's economic and environmental impacts over time;
- Analysis of the impact and estimates and, where necessary, formulation of new strategies to mitigate adverse impacts; and
- Recommendations for research and development where impacts cannot be predicted with adequate confidence.

Impact Assessment Model

The IAM accepts as input a comprehensive scenario which specifies the economic, environmental and energy supply assumptions for the future.[6] To compress the size of the data bases required, the IAM treats the individual utility firms in a given state as though they were one of two firms; one investor-owned, the other publicly-owned. The IAM operates each such state "firm" over the required time period under the selected scenario conditions in order to identify its economic and environmental behavior. The fundamental structure of the IAM is shown in Figure 2. It consists of six principal processing components:

- The DEMAND component converts a scenario-specific national demand for electricity (specified by growth rates in both peak and energy use) into demand for each state-firm, considering specific state population growth rates. Also, it projects peak and overall energy demands that will have to be met entirely by generation owned by the state-firm as well as projecting the state-firm's future levels of retail and wholesale sales and purchases.

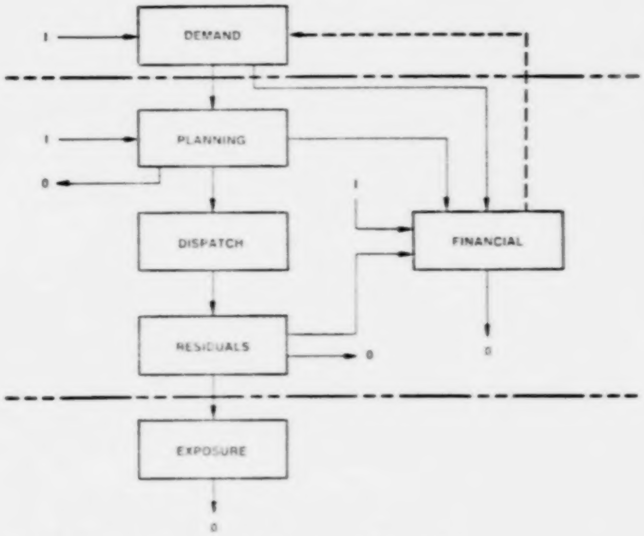
DEMAND
PLANNING
DISPATCH
RESIDUALS
EXPOSURE
FINANCIAL
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Figure 2. The impact assessment model

- The PLANNING component projects the technical characteristics that the state-firm must have in future years to meet demands, beginning the projection with existing systems and current plans and considering energy and environmental restrictions. In addition, it projects the state firm's fuel choices and pollution-control strategy, estimating their impacts on the firm's generating capacity and on the need for new construction to replace lost capacity.

- The DISPATCH component apportions energy production among the state-firm's different types of generating facilities on the basis of least marginal operating cost, considering the load patterns of typical days in different seasons as modified by the scenario's specification of either future improvements or future deterioration of system load factors.

- The RESIDUALS component projects the state-firm's actual usage of specific fuel, using the technical characteristics projected by PLANNING and the production allocations assigned by DISPATCH; then it determines the resulting releases of pollutants into the environment. It also, projects the firm's water consumption. In estimating the release rates it considers an extensive list of air pollutants and solid wastes.

- The FINANCIAL component projects production expenses (from DISPATCH and RESIDUALS) with construction expenditures both for new productive facilities and for pollution control (from PLANNING) and with projected sales and power-purchase levels from DEMAND. By using data on the state-firm's financial status in the base year, it projects the firm's balance sheet earnings statements, sources and uses of funds and other financial statistics.

These computer models interact so as to give economic impacts at the state and national level for:

- capital requirements (new facilities, pollution control)
- electricity prices and utility revenues
- utility operating costs
- capacity mix
- other financial data.

and environmental impacts at the county, state and national level for:

- fuel consumption
- rates of pollutant releases
- population-at-risk distributions
- consumption of process and cooling water at critical points in fuel cycle

These results are made available for analysis by the Air Quality Impact Assessment Model (AQM).

Air Quality Impact Assessment Model

The AQM, still under development,[7] forms the analytical link between the pollutants emitted to the atmosphere and populations exposed to primary pollutants (those directly emitted) and secondary pollutants (those formed in the atmosphere from other pollutants). The first function of the AQM is to analyze the IAM's projected primary pollutant releases according to:

- unit age
- probable release height
- season
- diurnal emission curve
- geographical distribution

The AQM then determines the volume of air available for pollutant dilution and reaction, the probable maximum impact sectors downwind, and the resultant sulfur dioxide and sulfate concentrations for selected regions of interest because of their current or projected high power plant emissions.

Meteorological analysis techniques utilized include:

- persistence analysis
- trajectory analysis
- synoptic air mass movement analysis
- sector box modeling
- multi-point source sector box modeling

Persistence analysis provides a relatively inexpensive approach to identifying those source-receptor situations which continue for ten to twenty hours. Analysis of synoptic air mass movements (stagnating anti-cyclones) identifies episodic conditions in which long-range transport plays a significant role. Trajectory analysis is applied to situations intermediate between these two extremes and for studying the movement of air parcels of particular interest within a stagnating anti-cyclone.

Scenario Element Description

Scenario elements for the ITA fall into the three general categories of environmental policy, energy policy and economic conditions. Because the energy policy element and the economic conditions element must be consistently specified for any scenario, it is possible to collapse these two scenario dimensions into one. Scenarios selected for analysis during the first phase of the ITA are shown in Figure 3.

ENVIRONMENTAL POLICY

- Control Policy
- Siting Constraints
- Control Technology
    - Relaxed Controls (LAX)
    - Business as Usual (BAU)
    - Clean Air Act Revisions (CAR)
    - Strict Precursor Controls (SPC)
    - Availability of Cleaned Coals

ENERGY FUTURE

- Fuel Policy
- Generation Technology
    - Reference (REF)
    - Conservation (CON)
    - Increased Oil Use (IOU)
    - Electrification (ELC)
    - High Coal Use (HCU)

(continued)

Figure 3

Scenario elements

Figure 3 (continued)

ECONOMIC CONDITIONS

- **Macroeconomic Conditions**
- **Electricity Demand**
- **Utility Financing**
- **Rate Regulation**
    - **Moderate Growth (MGR)**
    - **High Growth (HGR)**

The four environmental policy elements studied are:

Relaxed Controls (LAX)

- Objective - To establish a financial baseline with which to compare the economic impacts of pollution-control alternatives. It is assumed that no federal legislation limiting air emissions has been enacted and that particulate emissions are subject only to moderate limitations under local ordinances.
- Policy Instrument - 90-percent removal of particulates from coal-fired boilers required by local ordinances.

Business as Usual (BAU)

- Objective - To illustrate a scenario of moderate control levels and costs. This alternative approximates current regulations for the control of pollution from steam electric plants.
- Policy Instruments - Current State Implementation Plans (SIPs) - Current New Source Performance Standards (NSPS)
  - Siting prohibited in nonattainment areas (areas in which there is presently an officially recognized violation of primary ambient air quality standards)
  - No mandatory control technology required for new sources other than what is required to meet NSPS.

Clean Air Act Revisions (CAR)

- Objective - To illustrate the impact of a Non-Significant Deterioration (NSD) policy reflecting proposed congressional amendments to the Clean Air Act. This alternative is characterized by a restrictive siting policy and by one interpretation of what constitutes Best Available Control Technology (BACT). Siting is prohibited in areas where deterioration of air quality cannot be tolerated (for example, national parks and other federal lands) and in nonattainment areas. Flue gas desulfurization is required for all new sources on line after 1981 as an integral part of a strategy to protect and enhance air quality.
- Policy Instruments - Current SIPs
  - Current NSPS
  - Siting is prohibited in Class I and nonattainment areas. Because siting is not allowed in any county that contains any part of a Class I area, an overestimate of land area proscribed from development is obtained.
  - For new sources on line after 1981, BACT is required for SO_2. This is interpreted to mean mandatory scrubbers having a 90 percent removal efficiency.

Strict Precursor Controls (SPC)

- Objective - To illustrate the potential impact of an air quality standard for sulfates through the use of very stringent controls on SO_2, particulates, and NO_x - precursors for which standards already exist. This policy alternative recognizes a regional approach to coal utilization, the need to better control existing sources in order to obtain significant near-term air quality improvement, and the desire to minimize scrubber retrofit costs where possible. It characterizes an interim sulfate strategy aimed at reducing sulfates through near-term reduction of SO_2 emissions without imposing extreme economic penalties on the utilities.
- Policy Instruments

  - SIPs are modified on a regional basis, making them stricter in the eastern and interior sections of the country. Emission limits are used and utilities are allowed some choice in meeting them, depending on the relative costs of using low-sulfur coal, cleaning coal or retrofitting scrubbers. The eastern regional strategy requires that SO_2 emissions be reduced to the minimum level achievable by physical cleaning of eastern coal. Utilities respond by cleaning local coal or retrofitting scrubbers. The Western strategy requires that SO_2 emissions be reduced to the level specified in current (already strict) SIPs. Naturally for new sources, BACT supersedes NSPS as an approach to the control of both SO_2 and NO_x. This means mandatory use of 90-percent efficient scrubbers and the use of combustion modifications to reduce uncontrolled NO_x emissions by approximately 60 percent. National policy would also require that NO_x be controlled by retrofitting existing sources with appropriate combustion modifications by 1985, such that current NSPS level of performance will be met. The policy also prohibits siting in Class I areas and nonattainment areas.

There are five energy policy elements studied:

The Reference element posits a baseline, with moderate growth in peak demand exceeding growth in energy demand by 0.5 percent. The future capacity mix reflects the utilities' forecasted capacity additions.

The Conservation element is an alternative similar to the Reference case in projected capacity mix but postulates an energy demand growth rate of 4.9 percent. Two variations are specified for peak demand: compared to the growth in energy demand, growth in peak demand is either (a) 0.5 percent higher, or (b) 1.0 percent lower.

The Increased Oil Use (IOU) element is similar to the Reference case except that future capacity additions reflect an increased use of oil.

The Electrification (ELC) element is similar to the Reference case but posits a higher growth rate [illegible] energy demand (6.4 percent). Here peak demand growth exceeds emergy demand growth by 0.5 percent annually.

The High Coal Use (HCU) element is similar to the Reference case except that any capacity additions beyond those presently announced reflect an increased reliance on coal.

The two economic condition elements postulated are a moderate growth rate and a high growth rate of GNP. Under the moderate growth rate of GNP, a rate of inflation characteristic of current economic conditions, and a moderate cost of debt are assumed. The high GNP growth rate case postulates a higher rate of inflation characteristic of a stimulated economy. It also assumes a higher interest rate for cost of utility debt.

For the analyses described in this paper all energy scenario elements except ELC assume a moderate economic growth rate, while the ELC scenario assumes a higher economic growth rate. These economic growth rate assumptions are consistent with historical experience. It should be kept in mind that this historical experience was gained over a period of declining real prices for electricity, and thus may not be a reliable guide for the future. Nonetheless, those factors which could be anticipated to drive electricity demand up are likely to produce the conditions contained in the high growth rate scenario element.

PHASE I RESULTS

Selected combinations of these scenario elements were fed into the IAM. The results of these scenario runs were analyzed for their regional implications, and appropriate use of the AQM was made to suggest where major developing problem areas for mid-range and long-range atmospheric transport of power plant pollutants will occur.

IAM Results

- HOW WILL ALTERNATE ENVIRONMENTAL POLICIES AFFECT REGIONAL COAL PRODUCTION?

Production of low-sulfur western coal will remain near capacity if existing sulfur dioxide limits stay in effect. Under current (1975) relative costs, and in the absence of major transportation constraints, the flow of coal into the Midwest will be substantial and will continue to grow. States east of the Mississippi that may import low-sulfur western coal to meet current SO_2 emission limits include Illinois, Indiana, Michigan, Wisconsin and Ohio. More stringent controls, such as those found in the proposed amendments to the Clean Air Act, may increase reliance on flue gas desulfurization and thereby substantially reduce demand for western coal under that predicted in this base case (REF/BAU). Nevertheless, the demand for western coal in 1990 is likely to rise to three or four times the quantity supplied in 1975, even under the strictest environmental control scenario.

The demand for coals of very low sulfur content, regardless of region of origin, is extremely sensitive to environmental policy. The current New Source Performance Standards bring the industry very close to the "breaking point," in the sense that further tightening will force widespread use of flue gas desulfurization for new units, thereby dropping the demand for low-sulfur coal significantly below the level otherwise predicted for 1985-1990. This result supports the coal industry's position that uncertainty about future SO_2 limits is hampering the development of new, capital-intensive, low sulfur-coal mines.

- HOW WILL ALTERNATIVE ENERGY AND ENVIRONMENTAL POLICIES AFFECT EMISSIONS OF AIR POLLUTANTS?

Existing SO_2 controls will not be sufficient to keep sulfur emissions from increasing nationally from 1980 to 2000. Tighter controls on new sources could keep total emissions "flat" nationally, even though there would be regional increases, particularly in the West. Revision of State Implementation Plans in the East and Midwest to force more extensive use of existing reserves of low-sulfur coals and coal washing technology could reduce total SO_2 emissions by 1985 to about one half of what they would otherwise be assuming only moderate growth in energy demand and without forcing widespread retrofitting of flue gas desulfurization.

The natural gas curtailment region (defined as Texas, Arkansas, Oklahoma, Louisiana, Kansas and California) will become an increasingly important source of SO_2 emissions. If current energy and environmental policies continue, this region's contribution to the nation's SO_2 burden will increase from 10 percent in 1980 to 22 percent in the year 2000.

Existing particulate controls are capable of constraining total national power-plant particulate emissions to a very slight growth rate over the 1980-2000 period, assuming only moderate growth in energy demand. Retrofitting of nitrogen oxide controls will be necessary to keep total emissions from power generation from increasing substantially between 1980 and 2000. Otherwise, under current control requirements NO_x emissions from power plants will increase by a factor of fifty percent during the 1980-2000 period.

- HOW WILL ALTERNATIVE ENVIRONMENTAL POLICIES AFFECT ELECTRICITY COSTS? (See Figure 4)

Under current air-pollution control requirements, approximately 54 percent of SO_2 emissions from power plants will be controlled by 1990. If very stringent controls are required, approximately 86 percent of SO_2 emission and 40 percent of NO_x emissions can be controlled. But the increase in per capita revenues required for power plant pollution control in 1990 for the more stringent controls will be double that required for current controls.

Assuming a relatively high rate of growth in demand for electricity and application of best available control technology for SO_2, per capita expenditures for electricity in 1990 will be approximately 20 percent higher than under current energy policy and relaxed pollution control requirements. Expenditures would be 25 percent higher under this increased electricity demand scenario combined with even more stringent environmental control requirements. These greater expenditures represent the combined effects of the increased costs to electrify and the cost of pollution control.

The increased investment required by 1990 for water-pollution control will be about the same as that projected for the current program of air-pollution control. Although unit costs of control are lower for water pollution than for air pollution, water-pollution control must be applied to both nuclear and fossil units, including some retrofit of existing plants. However, because operating costs for water-pollution control are small compared to those for air-pollution control, the increase in required revenues is considerably lower.

Results similar to these are available on a state and regional level, where special circumstances may produce variances from these national trends.

- WHAT ARE THE BENEFITS OF INCREASED USE OF CLEANED COALS?

Mechanical coal cleaning (washing), with an average energy recovery of 88 percent, can substantially reduce the need for flue gas desulfurization under current emission limits. For example, under present energy and envionmental policies, coal cleaning can reduce the fraction of coal-fired capacity needing flue gas desulfurization in 1990 by more than half. This reduction would result in a significant decrease in the amount of scrubber sludge to be disposed of near power plants, but would entail a substantial increase in the amount of coal cleaning waste to be disposed of near mine sites.

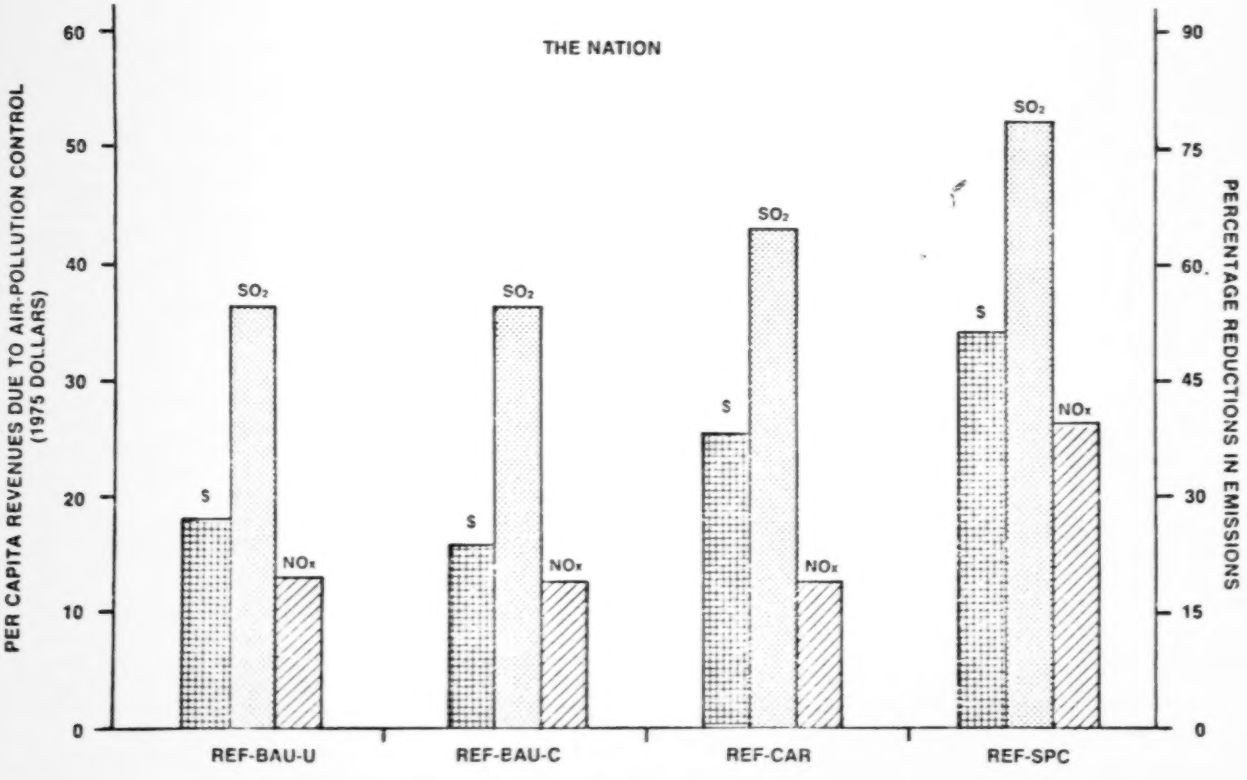

Figure 4. Per capita costs in 1990 with related emissions reductions under progressively strict controls

National per capita expenditures for air-pollution control under both current energy policy (which assumes a relatively high future dependence on nuclear capacity) and a policy of high coal use will be less in 1990 if industry expands its use of cleaned coals. The cumulative revenues needed from 1976 to 1990 to cover the costs of air-pollution control (on a national level) if coal cleaning is expanded will be about $4.5 billion less under a high coal use policy. The savings are due to the difference between the costs of using cleaned coals and the costs of using uncleaned coals plus flue gas desulfurization. Regionally, this use of cleaned coals will have its greatest impact on the eastern third of the United States. Under current energy and environmental policies, the clean coal demanded in 1990 will amount to 94 million tons, compared to the 93 million tons, of run-of-mine coal that were mechanically cleaned in 1974.

Much of the currently cleaned coal is produced for the metallurgical coal market. None of the existing steam coal cleaning facilities are designed or operated to optimize sulfur removal. Thus, there exists a large potential for Appalachian coal to meet moderate SO_2 emission requirements if the required investments in mechanical coal cleaning facilities were made.

° HOW WILL ALTERNATIVE ENERGY AND ENVIRONMENTAL POLICIES AFFECT THE GENERATING MIX?

Current utility plans for installing new baseload generating units by 1985 imply a growth in electricity demand which exceeds that used in all the scenarios but the ELC. Consequently, there may be a considerable deferral of planned units beyond the dates announced by the affected utilities, and this dampens the emphasis postulated in the scenarios on either coal or nuclear capacity to come on line after 1985. Under current emission limitations, and with peak demand continuing to grow more rapidly than average demand, a shift toward coal use at the expense of those nuclear units not already in the planning stage will not have a great impact on total controlled emissions. For example, SO_2 emissions will be up 12 percent in 1990 and up by 20 percent in 2000.

Should the growth rate of peak demand continue to exceed that for average energy demand for electricity, increased oil use combined with current air-pollution controls will cut costs. Compared with the current energy policy and relaxed controls, this high-oil-use future will require a smaller increase in analyzing per capita revenues than will result from the current energy policy and existing controls. The greatest impact of these cost savings will be felt in the eastern United States and in the natural gas curtailment region.

° WHAT ARE THE FINANCIAL AND ENVIRONMENTAL IMPLICATIONS OF DEMAND MANAGEMENT THROUGH ELECTRICITY CONSERVATION AND LOAD FLATTENING? (See Figure 5)

With current pollution controls, energy conservation initiatives aimed at flattening load peaks may actually increase SO_2 and particulate emissions, assuming coal-fired units will continue to supply a good share of baseload capacity. This increase in emissions results from the relative increase in use of existing plants that have a higher emission rate per unit electricity produced than new plants built to meet increased peak loads would have.

Reducing the peak and average demand electricity and requiring stricter air-pollution controls than those currently in effect in order to curb increased emissions from load flattening would result in a reduction of per capita revenues required in 1990 by more than $20, compared to what they would have been under current energy policy and no increased stringency of air-pollution control requirements. With no increase in pollution control requirements, the reduction in per capita revenues required in 1990 would be greater than $80 due to load flattening.

Thus, the current interest in reversing the present trend for peak demand to grow faster than average electrical energy demand must be combined with positive steps to reduce the rate of pollutants released per unit of energy produced from existing plants in order for this "conservation" measure to have a favorable impact on air quality. The potential revenue savings from load flattening is more than sufficient to pay the increased environmental control costs if excessive load management costs can be avoided in achieving this goal. Yet, because the regulatory mechanism for regulating pollutant emissions is entirely different from that for initiating load flattening measures, there is no assurance that the "saved" revenues would be available for increased pollution control, or that the increased controls would even be required of these plants. This situation is further complicated by the fact that these "saved" revenues will not actually be collected under the load flattening scenario because the extra capacity would not be built and put into the rate base. It may be easier in many jurisdictions to raise rates for new capacity additions than to clean up the emissions from older generating plants.

These and other similar results obtainable from scenario analysis by the IAM are useful for detailing what regional and national problems may emerge due to the operation of electric utility energy systems over the remainder of the century. But more analysis is required to outline their full extent. The AQM plays an essential role in the critical area of atmospheric conversion and transport of power plant related emissions.

AQM Results:

The focus of this discussion will be on the sulfate problem currently experienced in the 24-state EPA-designated sulfate region. More

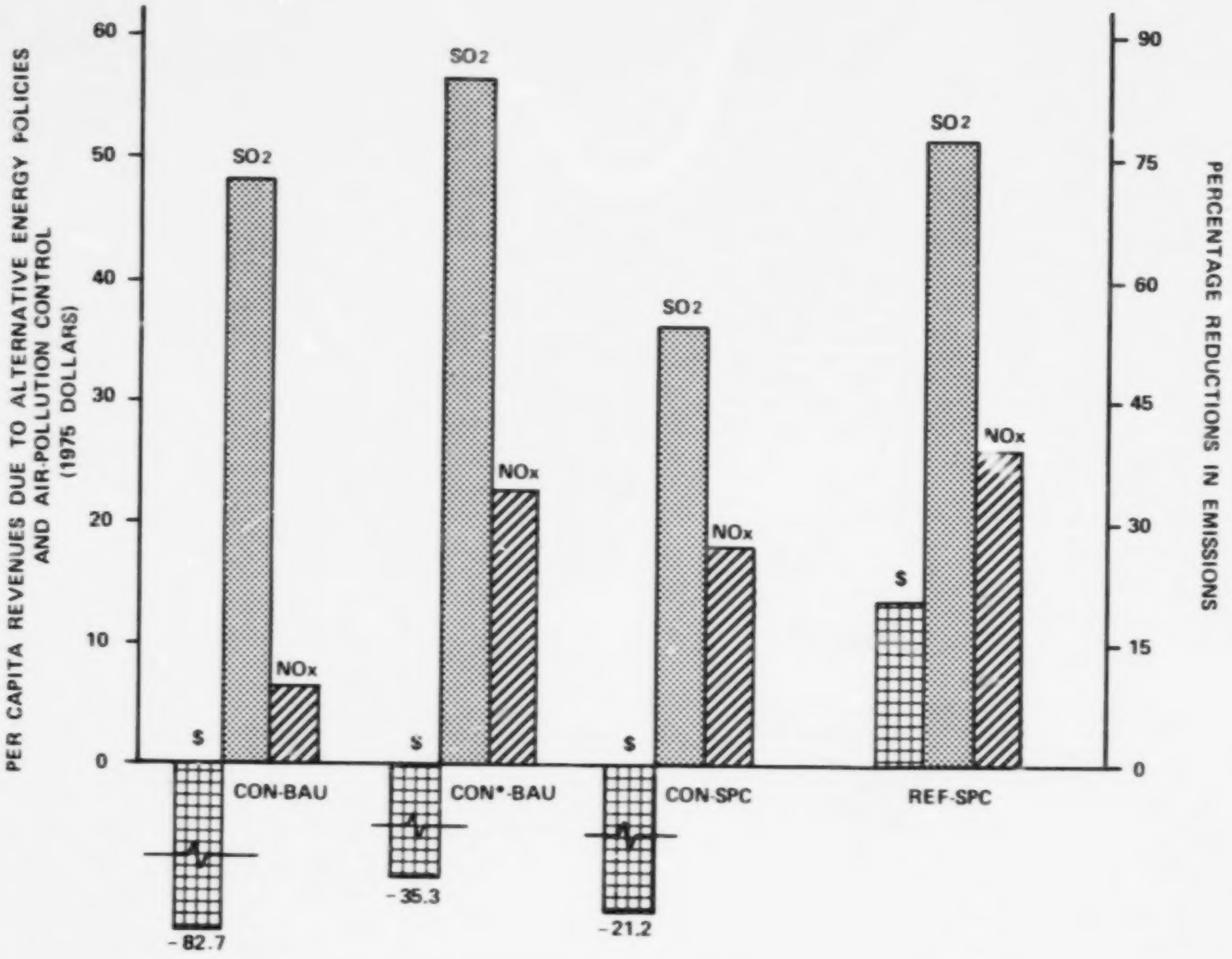

Figure 5. Per capita costs in 1990 with related emission reductions under load flattening

research results on the formation and transport of sulfates must be obtained before a definitive policy for sulfate control can be developed. However, the IAM and AQM are capable of providing information to assist EPA in the formulation of interim sulfate policies. The IAM and AQM can help define those geographic areas where presently acceptable sulfate levels may become unacceptable and where presently unacceptable levels may become intolerable.

It can help identify those areas which contribute to the sulfate problem and those which are recipients of the problem, and how this mix might change in the future under alternative energy and environmental scenarios. It can help rank areas according to their need for regulation, and can suggest which specific policies are most appropriate for local, state and/or Federal implementation. In summary, the IAM and AQM have the capacity to analyze future trends in sulfate concentration levels in order to identify the location of future problems so that EPA can develop priorities, policy options and implementation strategies most appropriate for each problem area.

Analysis of emerging sulfate problems and the development of EPA initiatives to deal with these problems requires that the following activities be undertaken:

First, it is necessary to identify those areas which currently experience excessive sulfate levels.

Then the future emission levels in each Air Quality Control Region (AQCR) of interest for the sulfate precursors, sulfur dioxide, nitrogen oxides, and particulates, and the resultant ozone concentration must be projected.

Next, those AQCRs should be identified where future sulfate concentrations will be comparatively high, given the present sulfate concentrations and future projections for precursor emissions and concentrations.

Thus, it is possible to designate AQCR "clusters" with future sulfate problems by taking into account the nature and extent of sulfate transport characteristics. This information should be sufficient to develop control strategies which are appropriate to the particular circumstances identified.

- WHICH AQCRs PRESENTLY HAVE HIGH LEVELS OF ATMOSPHERIC SULFATES?

The AQCRs with the highest measured sulfate concentrations in 1974 have been idenitified. Sulfate concentrations were collected for the thirty-four states comprising the expanded EPA sulfate region and the natural gas and curtailment region (California, Texas, Oklahoma plus the 31 easternmost states). Over half of the AQCRs in this study area either have no sulfate data or their data are unreliable. (AQCR data had to be available for six or more months of the reporting year, including at least three of the four seasons, before it was considered reliable.)

Those AQCRs where data on sulfate concentrations are missing and those where reporting is inadequate have been identified.* To permit more accurate assessment of the extent of the current sulfate problem and to accurately monitor sulfate levels in the future, EPA and the states will have to upgrade their measurement capabilities in those AQCRs for which inadequate sulfate data are available.

- WHAT ARE THE PROJECTED FUTURE EMISSION LEVELS OF SO_2, NO_x AND PARTICULATES FROM POWER PLANTS?

AQCRs with high SO_2 concentrations reported in 1974 have been compared with the geographical distribution of those AQCRs with the greatest projected increases of SO_2 emissions from power plants between 1980 and 1995 as well as with the highest projected increases in NO_x particulate emissions for these years. While the present sulfate problems are most severe in the Ohio River Valley, the greatest increases in future sulfate precursor emissions are concentrated in the south central portion of the country. Analysis of these emission projections relying on existing sulfate regional problem areas for insights suggests that the significant increase in coal use anticipated in the south central states may produce a new sulfate problem region.

- WHICH AQCRs ARE LIKELY TO EXPERIENCE OR TO CONTRIBUTE TO HIGH REGIONAL CONCENTRATIONS BY 1995?

The identification of future high sulfate regions and the development of appropriate control strategies can be analyzed more readily by identifying those AQCRs that are likely major donors and/or recipients of atmospheric sulfates. This is not to say that locally generated precursor emissions do not contribute to local sulfate problems. It is clear, however, that some areas which produce only modest amounts of precursor emissions experience disproportionately high levels of sulfates due to a downwind location from major donor areas--the "long-range transport" problem.

Sulfate problem areas include AQCRs which emit high levels of precursors as well as those which may have low precursor emissions but high sulfate concentrations because of a downwind location with respect to a donor AQCR. An effective strategy must recognize that there are both villains and victims with respect to atmospheric sulfates and effective regulatory policies require that both be identified and linked, one to the other. Sulfate concentrations and precursor emissions data are combined on an AQCR level with characteristics regarding power plant stack height and the existence of meterological conditions favorable to long-range transport. An unambiguous designation of "donor" or "receptor" is not possible in all cases yet many such classifications of AQCRS can be made for sulfate analysis purposes. The highest emission counties for precursor emissions (SO_2 and NO_x) under a large number of alternate scenario combinations have been identified. These counties, which also tend to have higher ozone concentrations, form the donor counties for analysis purposes.

- WHAT CLUSTERS OF CONTIGUOUS AQCRs CAN BE IDENTIFIED WHICH MAY HAVE HIGH FUTURE SULFATE CONCENTRATIONS?

Three major and two minor clusters have been identified. The first major cluster, from Illinois eastward to Pennsylvania and New York suggests a reinforcement of the existing sulfate problem. The second cluster appears in the southeast where isolated sulfate problems at present can be expected to spread, compounded by the relatively frequent air stagnation due to anticyclonic atmospheric conditions. The third cluster suggests an emerging sulfate problem in the south central states, forming from emissions generated in Texas and Louisiana. The growing AQCR clusters imply deteriorating sulfate conditions in the future under a wide range of scenario assumptions, unless corrective control measures are applied.

CONCLUSION

This selection of results are indicative of the capabilities of these analytical tools. They are especially adaptable to answering questions such as: What are the expected changes in sulfate levels in 1990 if the New Source Performance Standard for coal-fired electric utility boilers for SO_2 emissions is changed in 1978? or, What are the economic effects on the industry of changed SO_2 and particulate New Source Performance Standards? Expansions and refinements now in progress will allow even more complex assessments to be accomplished in the near future.

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*Oklahoma, Iowa, Virginia, and West Virginia are four states in the study area which contain no AQCR with reliable data.

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INTEGRATED ASSESSMENT

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INTRODUCTION

The Tennessee Valley Authority (TVA) is responsible for many regional development programs. Its fertilizer development program is national and international in scope, and its electric power system, which will have a generating capacity of 30 MWe by the end of 1977, is the largest in the Nation.

A number of analysis processes are involved in (1) forecasting energy needs in a large (207,200-km^2) region, (2) planning and designing systems, (3) constructing power plants and transmission lines, and (4) operating the complex system economically. Because all these tasks must be accomplished within a stringent legislative and regulatory climate, there is a need for methodologies that will improve and accelerate analysis processes wherever possible to avoid the diseconomies of delay. Developing such methodologies is TVA's purpose in the three tasks selected under the Environmental Protection Agency (EPA) pass-through Integrated Assessment program. The sequential objectives of the three projects, in precis form, are as follows:

1. To improve methods of forecasting the amount of electric power that will be needed and the time and place at which that power must be supplied.
2. Given the alternative systems implied by task 1, to develop better models for expressing the residuals from each alternative.
3. Given the residuals, to develop better methods for reiterative impact and cost analysis--in this case, to explore interactive computer graphics as a means to expedite analysis work.

DEVELOPMENT OF A REGIONAL ECONOMIC MODEL

During the late 1960s, considerable emphasis was placed on developing national and regional economic models, but for various reasons, most of the regional models did not prove useful as practical planning tools. Development of the TVA model is based on experience gained in this earlier work.

Economic development and change in a region depend on national, regional, and local forces, and certain interactions of policies and programs within the region can (1) change the set of national-regional relationships or (2) cause the total change in the region to differ for a given set of national-regional relationships. Consequently, an interrelated system for making long-range forecasts of economic and demographic factors (population, households, employment, and income) is necessary to account for these interactions and to give some dimension to the changes in results that are expected from changes in the key variables. The TVA economic simulation model was developed and is being expanded to (1) account for the impact of national and regional forces on the regional economy and, subsequently, energy demand and (2) determine the potential effects of policies and programs on regional conditions. For example, changes in population and employment are sensitive to changes in national and regional conditions; but the degree of sensitivity of those changes and the effects they may have on energy demand are unknown. How will an increase or decrease in family size or a national increase or decrease in employment impact an industry that is energy-intensive (primary metals) as opposed to one that is nonenergy-intensive (apparel)? What can be expected to happen to the region if better highway linkage is provided to surrounding markets, relative wage costs change, or relative energy costs change?

Answers to these and similar questions are essential for planning energy (and environmental) systems. Therefore, our specific objective is to develop a model that will (1) provide a consistent annual set of long-term economic and demographic projections that reflect anticipated changes in the business cycle; (2) assess regional sensitivity to national economic variables such as growth or decline in specific industries; (3) assess the impact in small (multicounty) areas of a large construction project (e.g., a large nuclear energy generating plant); and (4) provide a macroeconomic data base at a multicounty level for land-use planning and site assessment.

Much of the conceptual work has been done, and an operational model has been developed for the TVA power service area (170 counties in parts of seven states). The model has been designed for the area as a whole or for homogeneous economic subregions for which input data can be developed. At the present stage of development, the operational model consists of two principal components: (1) a submodel for population, labor force, and households and (2) a submodel for employment. Output of the current model consists of population by age (six categories) and race (two categories), net migration, labor force, households, and employment in six manufacturing and five nonmanufacturing categories.

Operation of the model revealed that it did not contain enough detail, especially in the employment categories, to satisfy the needs of energy system planning; projections for the energy system depend on such factors as whether growth will occur in aluminum plants (energy-intensive) or metal fabrication or apparel plants (not as energy-intensive). Therefore, recent developmental work has concentrated on improving and expanding the manufacturing portion of the employment submodel.

The goal of the recent work was to expand the model to include the two-digit Standard Industrial Classification (SIC) level of detail in the manufacturing sector. Equations have been formulated by econometric techniques for the 20 two-digit SIC manufacturing industries. Preliminary versions of these equations have been inserted into the model. Figures 1 and 2 compare actual employment growth in the power service area with the growth predicted by the model for some two-digit SICs for the period 1960-1974 and show the model's annual projections to the year 2000 based on a certain set of assumptions about national and regional economic conditions.

Work is also in progress to improve the formulation of the migration equations used in the submodel for population, labor force, and households. Because the South recently has experienced significant immigration, which affects population size and the number of households, improving that portion of the model is important to provide better estimates for energy system planning. Work is also in progress to improve the trades and services portion of the employment submodel.

At its present stage of development, the model provides projections for the power service area and allows assessment of the region's sensitivity to national economic conditions. However, additional research and development are necessary before the model can provide the maximum potential input into planning energy and environmental systems. Planned research and development consists of (1) developing a submodel for personal income; (2) adapting the model to quantify, at a multicounty level, the impacts of an incremental expansion to the energy generating system on population, labor force, and employment; (3) developing and adding to the model an algorithm for allocating multicounty projections to smaller areas (counties) to (a) ascertain energy requirements related to land use and (b) determine impacts of expansions in the energy generating system; and (4) developing data and methodologies to identify growth differentials between counties or groups of counties because changes in growth relate to local capacity for accommodating socioeconomic impacts.

POWER SYSTEMS RESIDUALS SIMULATION MODEL

Long-range electric utility planning involves a large number of interrelated activities based on one or more economic scenarios: fuel cost forecasting, plant capital cost forecasting, load forecasting, system expansion planning, system operation planning, financial planning, and environmental planning. These are not isolated functions nor are they meant to be all-inclusive, but they are the principal tasks associated with long-range planning. The relationship between the functions is illustrated in Figure 3.

These planning functions are generic in nature and are performed by all electric utilities to some degree. Most can be aided by mathematical modeling techniques. TVA is developing the Power Program Integrated Planning Model, which represents these functions and the relationships between them in detail.

The operation of an electric power system produces a number of residuals such as ash, waste heat, oxides of nitrogen (NO_x), and sulfur dioxide (SO_2). The Environmental Planning Model predicts

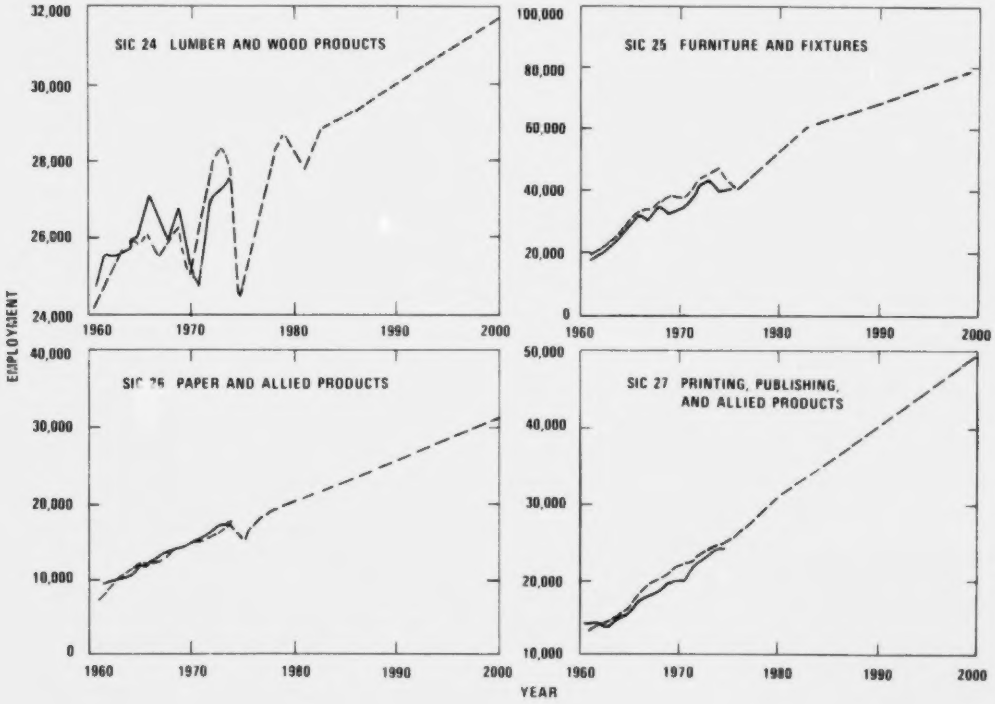

Figure 1.

Comparison of actual employment in the TVA power service area for the period 1960-1974 with employment generated by the model for SICs 24, 25, 26, and 27. Annual projections by the model to year 2000 are also shown.

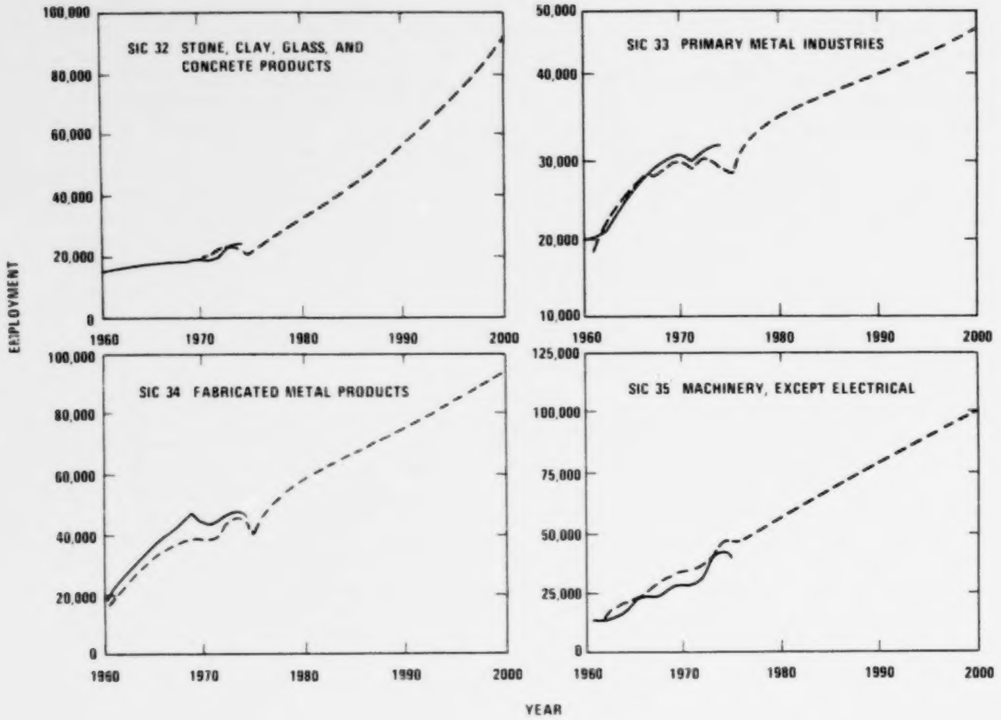

Figure 2.

Comparison of actual employment in the TVA power service area for the period 1960-1974 with employment generated by the model for SICs 32, 33, 34, and 35. Annual projections by the model to year 2000 are also shown.

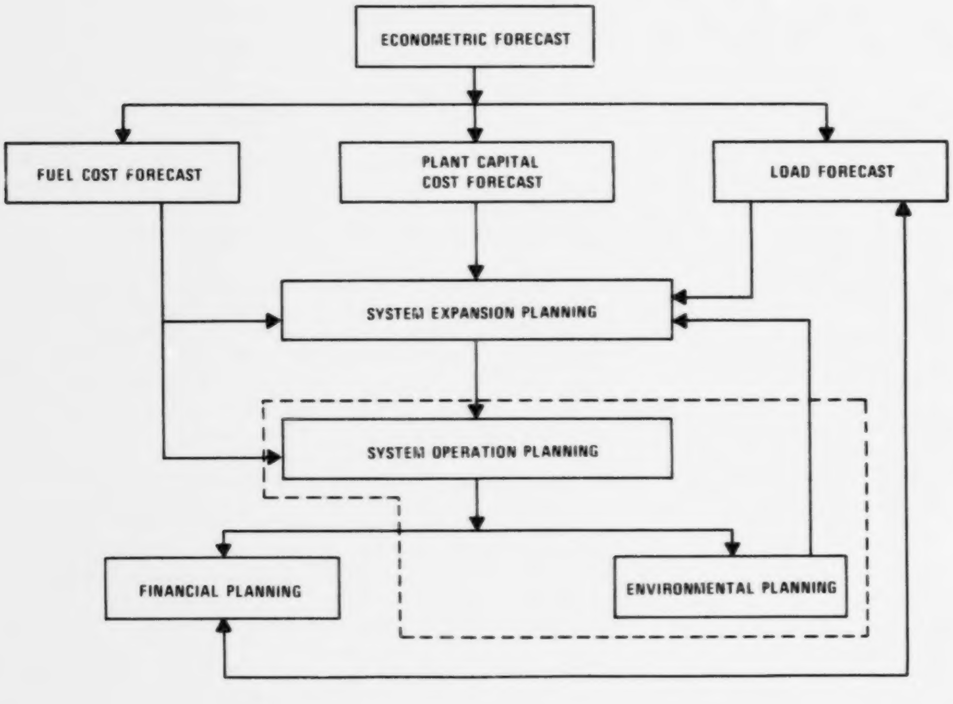
ECONOMETRIC FORECAST
FUEL COST FORECAST
PLANT CAPITAL COST FORECAST
LOAD FORECAST
SYSTEM EXPANSION PLANNING
SYSTEM OPERATION PLANNING
FINANCIAL PLANNING
ENVIRONMENTAL PLANNING

Figure 3.

Relationship between elements of long-range electric utility planning.

the residuals produced by a particular configuration of the power system on a plant-by-plant basis and provides inputs for detailed dispersion models to assist environmental evaluation of expansion and operating policies of an electric power system. The main thrust of the design and development of this model is to create a set of functional relationships that link expected energy (in British thermal units) consumed by a power plant to the expected amounts of residual emitted by that power plant over a specified time.

This research has concentrated primarily on formulating transformation relationships for SO_2 and gross particulates because of the ready availability of field data. Although other air-contaminating residuals, such as NO_x, have been investigated, no transformation equations have been developed for them. The computer model has been completed and is operating with test data on a stand-alone basis. The file interface with the rest of the Integrated Planning Model has not been completed.

We had planned to (1) extensively investigate water pollutants and NO_x, (2) incorporate load-shaping techniques and the capability of modeling the derating of plants, (3) expand the environmental reporting model to include a more comprehensive list of residuals, and (4) conduct a demonstration of the use of this model for power systems planning. However, because of staffing difficulties, this work has been postponed indefinitely.

APPLICATIONS OF COMPUTER GRAPHICS TO ENVIRONMENTAL ANALYSIS

For more than a decade, architectural, aeronautical, civil, and mechanical engineers have benefited from analytical applications of computer graphics, or "computer-aided design." However, a surprisingly small amount of program funding and technical ingenuity has been applied over this same period to nonstructural engineering applications. The need for recasting many analyses that supply input to the preparation of comprehensive environmental impact statements (such as for nuclear power plants) has provided a focus for developing environmental science and engineering applications of computer graphics. We found that most efforts to apply computer graphics to environmental analysis have been limited to geographic or mapping applications; techniques of direct benefit to environmental engineers or scientists have hardly been exploited.

The intent of our research is to investigate and develop applications for computer graphics that can contribute directly to reducing delays in assessing the environmental impacts of building and operating power generating systems. This work is being performed against the backdrop of practical analysis applications experienced during the course of energy system planning, design, and operation by TVA, the Nation's largest producer of electric power.

A truly integrated approach to assessing the environmental impacts of power generating systems requires the timely consideration of (1) alternative methods of pollutant control, (2) the dispersal of pollutants in the environment, (3) human health, (4) ecosystem impacts, and (5) the attendant costs and benefits. Many analyses involved in the assessment process can be performed conveniently by using the computational and data management capabilities of the computer. The full potential of the computer has not been realized because of a sizable delay between the time an analysis is requested and the time the processed information is presented in suitable form to the engineer, scientist, or manager.

This delay has resulted from two causes. First, computer job processing was commonly conducted in a batch mode: Computer programs and data were keypunched and submitted to the computer for processing; the output was returned to the user at some later time, completing only a single iteration. A second cause for delay was that the results were commonly presented in tabular form or in some form selected before the analysis was begun. If the results of the analysis suggested presentation of the data in some format (graphic or tabular) other than the one selected, the analysis had to be rerun or the data display had to be completed manually.

Although time-sharing computer systems have greatly reduced the time involved in running computer programs, interactive graphics terminals have opened up new possibilities for accessing the power of the computer. Results of an analysis can be viewed immediately as a graph, picture, or map on a cathode ray tube (CRT). The type of display, its orientation on the screen, and the particular data to be shown can be readily selected. A hard copy of the information on the screen can be obtained at the touch of a button. Interactive computer graphics allows the engineer or scientist to concentrate more on the meaning of the analysis and less on the tasks of data presentation and management.

During the first year's research, the state of the art was reviewed to determine existing applications of computer graphics to environmental assessment, graphics hardware and software capabilities, and computer graphics techniques that may be used in environmental analysis but have only been applied to other types of engineering analysis. An inventory was compiled of 53 potential demonstrations of computer graphics having direct application to the needs of TVA. Direct-view storage tube computer terminals used with conventional time-sharing systems were selected for the initial development of demonstrations because of their moderate cost and the availability of well-developed software packages.

One significant group of demonstrations using computer graphics is oriented toward the visual display of environmental data. Interactive multipurpose plotting routines have been developed for conventional x-y plots, contour plotting, and three-dimensional data presentation. These routines allow the investigator to readily tailor the display to a particular need. Figure 4 shows a typical plot of aquatic data from TVA's thermal effects studies for the Federal Water Pollution Control Act, Amendments of 1972, Section 316(a). The total time to produce final plots over the life of this project has been reduced from an estimated 176 man-days, when manual techniques are used, to 8 man-days, when interactive computer graphics are used.

Figure 5 shows a form of data display that could not be accomplished easily without the aid of computer graphics. This figure is a three-dimensional surface representing the distribution of dissolved oxygen in the vicinity of the thermal discharge from a TVA coal-fired steam plant. The investigator can rotate, tilt, and rescale the figure to select the display that communicates its features best (Figure 6). Extensive use has been made of this technique for displaying the physical, chemical, and biological quality of water with respect to time and space, distribution of air pollutants, and geologic and topographic information that is important for some environmental analyses.

A second group of demonstrations that have been developed involves application of computer graphics to analysis of socioeconomic impacts. The development of a methodology for screening potential sites for power plants according to socioeconomic criteria has been underway for two years. During the first year a review was conducted of the state of the art of identifying and measuring socioeconomic impacts of large-scale construction of power plants. TVA's procedures for analyzing socioeconomic impact and mitigation were also reviewed. The capabilities of a computer graphics analysis system that are needed to assist with these analyses were identified.

Twenty-two counties in East Tennessee were selected for testing a screening methodology. Data were collected at the county level on 24 socioeconomic indicators. These data were then incorporated into a data base that could be manipulated by interactive analysis and graphics display routines.

Selected indicators were combined mathematically to form capacity indexes, thus reducing the number of indicators to manageable size and providing a better measure of the potential for each county to absorb or benefit from a particular type of impact. Graphical and statistical methods were used to evaluate the relative merits of each new index formed. Resulting from this work were six indexes for (1) public service, (2) planning and public administration, (3) health, (4) education, (5) growth absorption potential, and (6) economic need. Finally, several forms of a composite index composed of these six capacity indexes were tested. Procedures were also developed to weight various indicators and capacity indexes in these analyses.

Three types of graphic displays were used in this research. Figure 7 shows the results of a program that draws any or all of the county boundaries being considered, identifies the county, and places a value or representative symbol within the

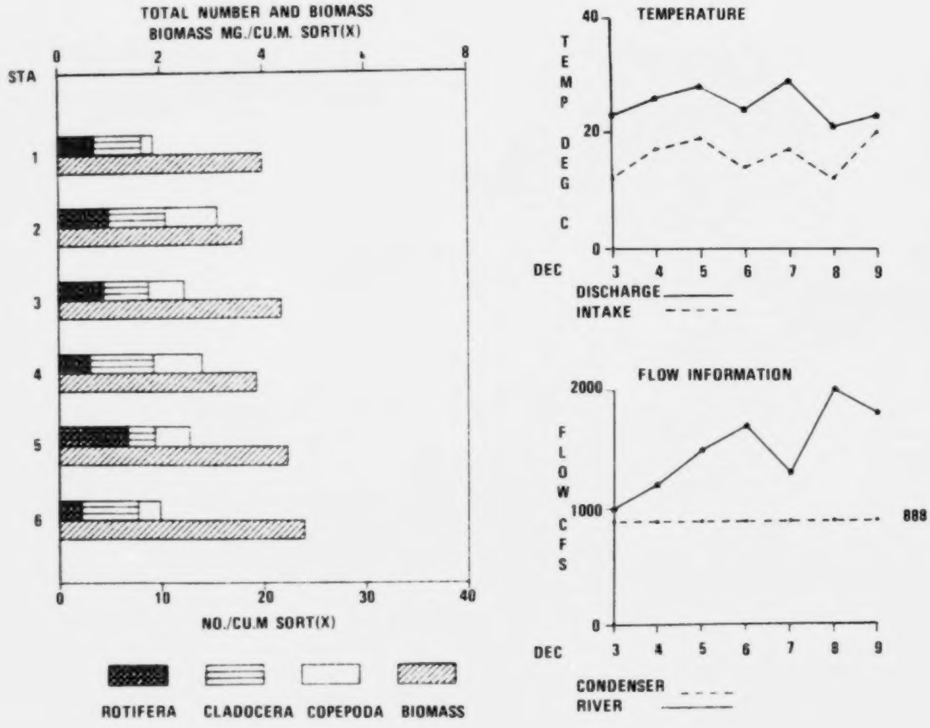

Figure 4.

Typical display of aquatic data used in reporting the results of TVA's thermal effects studies. The time required for manually preparing this type of display over the life of these studies is estimated to be 176 man-days. Using computer graphics has reduced this time to 8 man-days.

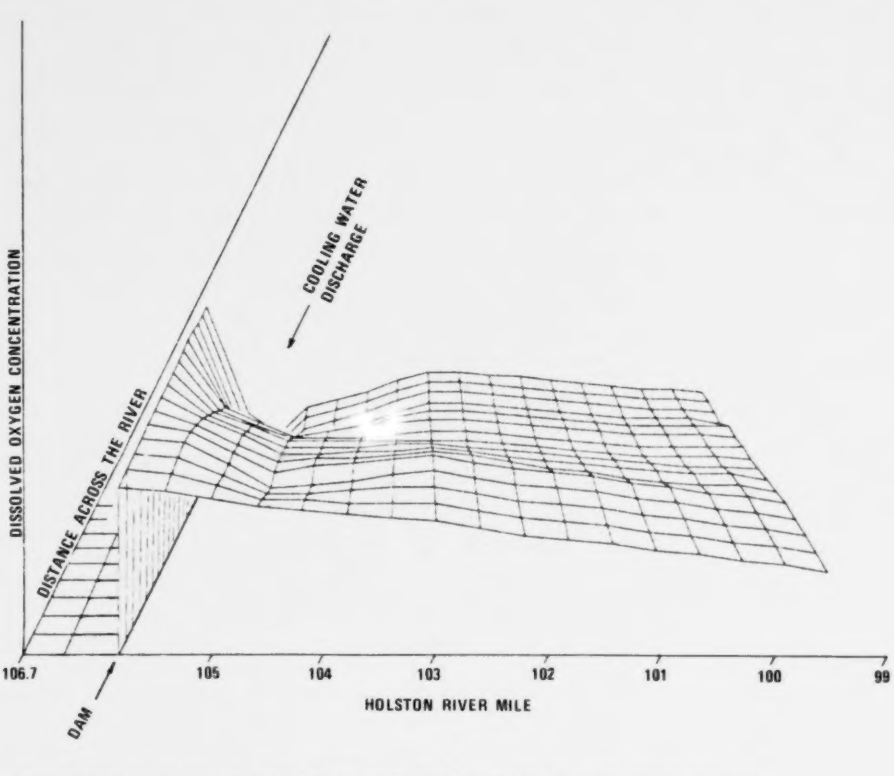

Figure 5. Enlarged and annotated three-dimensional view of water quality along a reach of river.

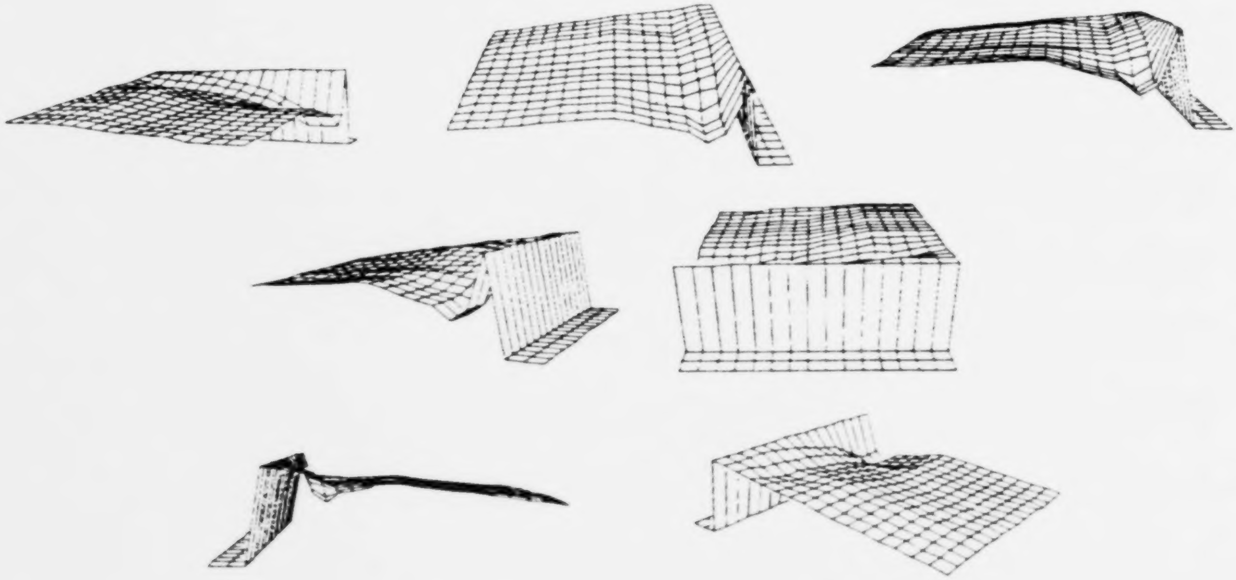

Figure 6. Three-dimensional views of water quality along a reach of river. The figure can be tilted and rotated by the person conducting the analysis until a view that best illustrates significant features of the data is obtained.

boundary. The map can be displayed at various scales, permitting a small portion to be selectively enlarged.

Figure 8 shows six socioeconomic indicators displayed in the general form of a Kiviat diagram. This graphical technique has been used for research in medicine, computer systems, and water quality, but has not been applied previously to socioeconomic analysis. The purpose of this display is to show on a single figure the rank or data values of a particular county with regard to several indicators. In the example shown, only six of the eight axes are used; the two vertical axes are not. The distance along each radius of each circle represents the relative rank of the indicator of interest among the counties considered in this analysis. For example, the county having the highest population living in urban areas would have a point on that axis plotted at a distance equal to the radius of the circle. The value for the middle-ranked county would be plotted halfway between the center and the circle's circumference, and the value for the lowest-ranked county would be plotted at some arbitrarily small distance from the center. When the resulting points are connected (including dummy points on the two unused axes), the resulting configuration takes the form of a butterfly for those counties that rank high on all indicators. Figure 8 shows the application of this technique to several counties in the test area. It is immediately clear that counties A and B rank substantially higher for the indicators selected than do, for example, C or E counties.

The value of this graphic technique depends on the ingenuity of the investigator to interpret the resultant configuration. If different numbers of indicators are used, different characteristic configurations are formed. Information about the system as a whole can be inferred from the symmetry, center of gravity, area, and shape of the configuration. The required flexibility for this analysis was made possible through the development of an interactive routine of graphics display.

Figure 9 shows one final type of useful graphics display. A scatter plot was used to display pairs of indicators whose correlation coefficients were unexpected or otherwise of interest. The entire set or a given subset of county data for the selected indicators can be readily plotted and the axes can be labeled automatically.

Another group of demonstrations uses routines of interactive analysis that interface directly with computer models. Figures 10 and 11 show the graphic results of two steps in an analysis of the distribution of air pollutants from mobile point sources. This simulation was needed to analyze probable impacts during the construction of a power generating facility. Various types of equipment (vehicles and machinery) that generate air pollutants can be distributed over the construction site in different patterns. Previously, this analysis was done by hand calculator; only a limited number of source configurations could be evaluated in a reasonable amount of time, and results were plotted by hand. Interactive graphics has made possible more rapid and accurate identification of potentially adverse situations and has provided much better analysis results on a more timely basis for court hearings involving potential impacts.

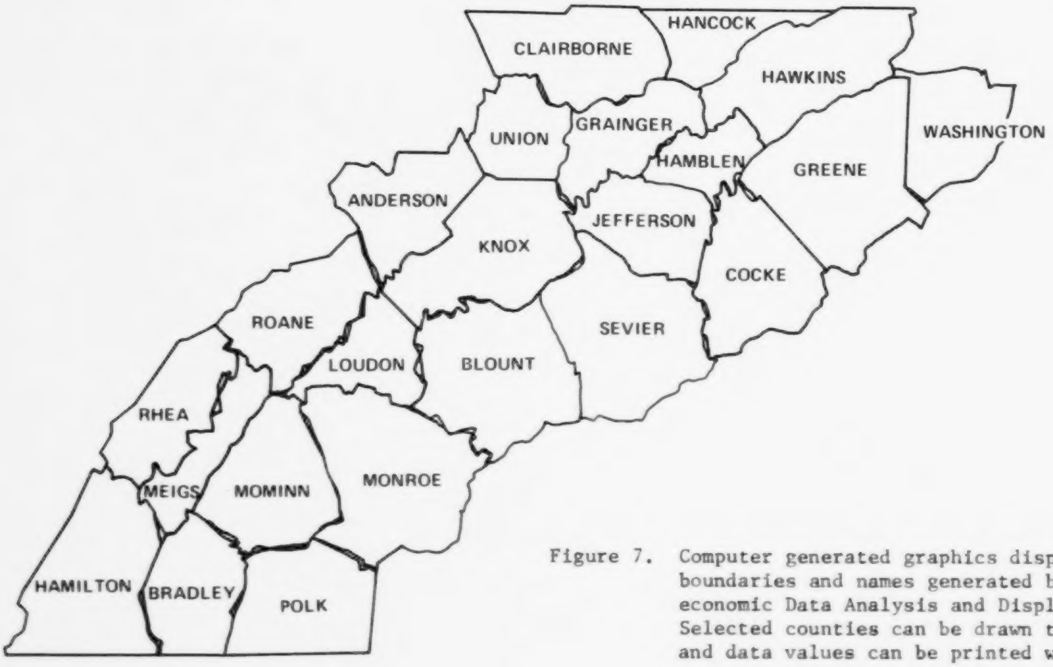

Figure 7. Computer generated graphics display of county boundaries and names generated by the Socioeconomic Data Analysis and Display Package. Selected counties can be drawn to any scale and data values can be printed with each boundary.

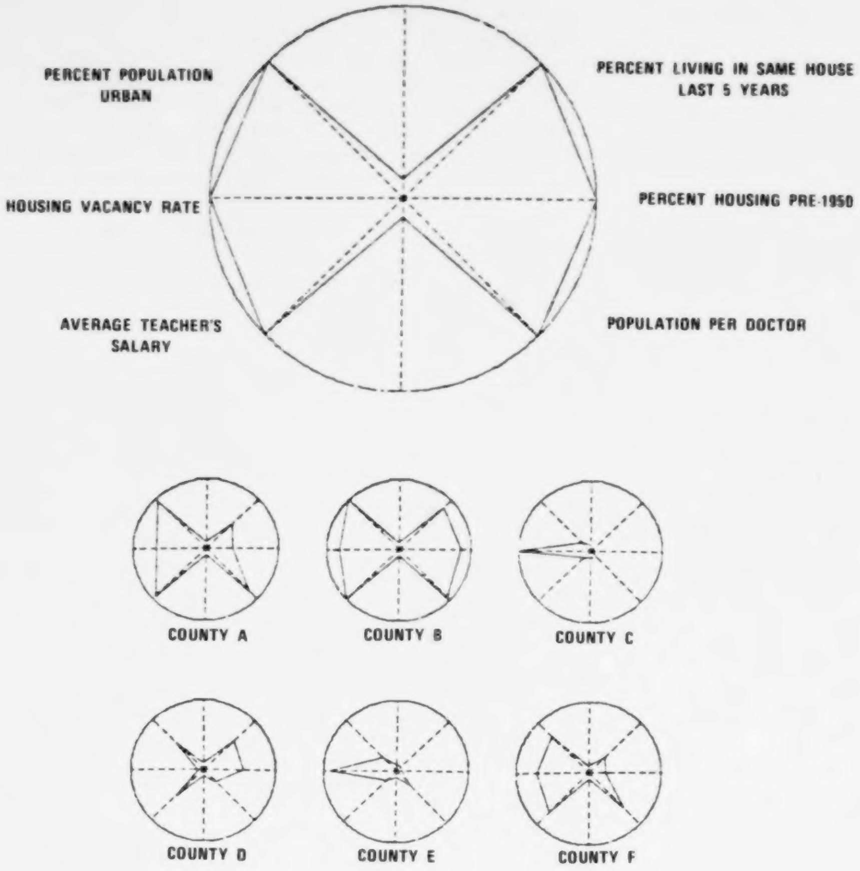
PERCENT POPULATION URBAN
PERCENT LIVING IN SAME HOUSE LAST 5 YEARS
HOUSING VACANCY RATE
PERCENT HOUSING PRE-1950
AVERAGE TEACHER'S SALARY
POPULATION PER DOCTOR
COUNTY A
COUNTY B
COUNTY C
COUNTY D
COUNTY E
COUNTY F

Figure 8.

Multivariate display of six county-level socioeconomic indicators. The results for six actual counties are given at the bottom. Relative rankings among a group of 22 counties in eastern Tennessee were computed for each indicator. Indicator values for each county were plotted so that the highest-ranked county was plotted at a distance from the circle's center equal to the radius and the lowest-ranked county was plotted at the circle's center. The more desirable the overall situation in the county with respect to these indicators, the more the configuration will be shaped like a butterfly.

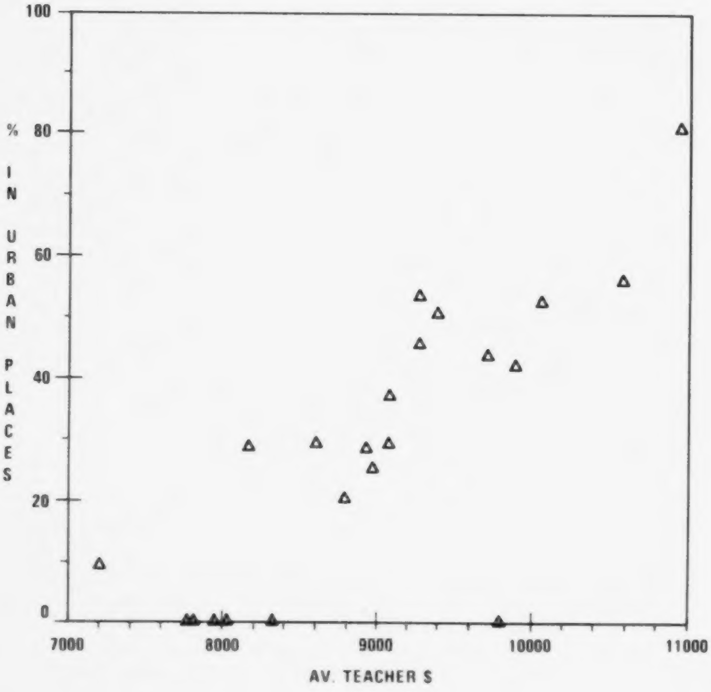

Figure 9. Scatter plot of two socioeconomic indicators generated by the Socioeconomic Data Analysis and Display Package.

EFFLUENT SOURCE LOCATIONS, POLLUTANT BEING EMITTED, AND METEOROLOGICAL ASSUMPTIONS

SOURCE	STRENGTH (G/SEC)	WIND SPEED (M/SEC)	STACK HEIGHT (METERS)	STABILITY CLASS (A–F)	SYMBOL
1	1000.	1.	10.	F	○
2	1000.	1.	10.	F	×
3	1000.	1.	10.	F	△

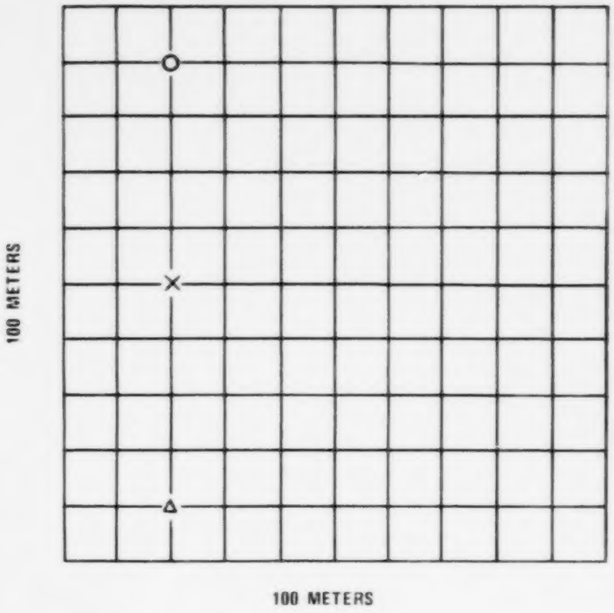

Figure 10.

Completed source grid with the interactive placement of three mobile point sources of air pollutants. See Figure 11.

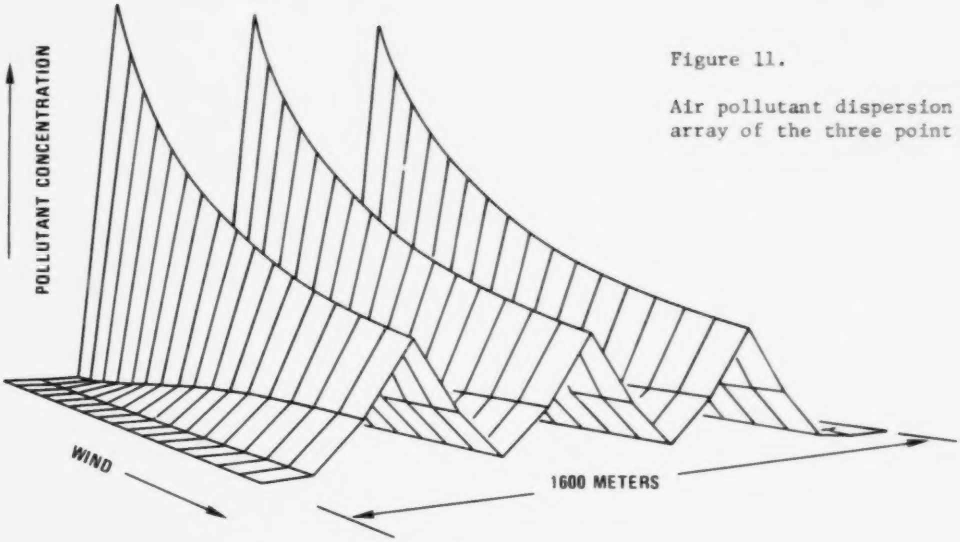

Figure 11.

Air pollutant dispersion downwind from the linear array of the three point sources shown in Figure 10.

Other interactive modeling routines developed are (1) three-dimensional (3-D) display of depth to bedrock in agricultural test plots, (2) 3-D display of variations in light intensity in an agricultural growth chamber, (3) 3-D displays of TVA reservoirs, years, and average concentrations of dissolved oxygen, (4) a system for reducing manual work in preparing special maps for site analysis, and (5) a general plotting routine to prepare graphs from data files.

Future demonstrations are planned for use with other types of computer graphics hardware. Refreshed graphics systems that permit dynamic manipulation of a display on a CRT will be used. Stand-alone graphics systems and intelligent graphics terminals will be investigated. Software development will stress demonstrating the practicality of interactive analysis that considers cost, pollution control alternatives, and environmental consequences. For example, a system is now being evaluated that combines existing models of air pollution control processes, transport of atmospheric pollutants, ecosystem impacts, and process design costs into an integrated analysis format so that the implications of environmental constraints or design control process decisions can be readily explored.

STATUS OF AN INTEGRATED ASSESSMENT OF COAL DEVELOPMENT

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INTRODUCTION

This integrated assessment of coal development is a key component of the project "Economic and Social Consequences of Coal and Oil Shale Development," which the Natural Resource Economics Division (NRED) and the Economic Development Division (EDD) of ERS are undertaking in cooperation with EPA. (Ref. 3) This status report concerns the major portion of NRED's work on the project.

An integrated technology assessment attempts to unify as much existing information as possible to determine major effects of applying a technology. (Ref. 5) Assessing coal development involves mainly the application of a familiar technology on a larger scale in some new geographic areas. Nevertheless, the potential for coal gasification and liquefaction means that new technology may be involved as well.

In structuring our assessment, we faced four general problems: 1) How comprehensive can we afford to be? Which topics should be integrated into the assessment, and which excluded? For any given topic, how much data and previous research are we able to collect and analyze given our project budget? 2) How is the information to be integrated? 3) How can we build into our integrating techniques the analysis of public policy options for coal development? 4) How can we phrase these options so they will be realistic and reasonable choices in the eyes of public policymakers? The analytical system we are constructing responds to these problems.

INTERREGIONAL COAL ANALYSIS

Coverage

We have drawn some clear boundary lines for the scope of our work, since it is not possible for us to assess every kind of effect of coal development. For example, we do not attempt to integrate information on human health, wildlife habitats, or Indian culture, important though these matters are. Instead, in the NRED portion of the work, we are integrating economic information on land and its use including agricultural use, water, coal reserves, coal mining, transportation, coal conversion technology, and coal demand.

Planned Output

Quantitative output from our analysis will be nationwide locational patterns of coal mining, transportation and processing, cost of coal production, the physical resources used, and the associated coal quantities and flows. As analytical inputs, alternative levels of total coal demand and alternative sets of public policies will be specified. Then a different locational, quantitative pattern will be provided for each actual or projected level of total demand for coal and each set of policy alternatives. Evaluation of the effects of the different coal demand levels and alternative policies will begin by comparing the different locational, quantitative patterns.

Projecting where and to what extent coal activity takes place under alternative assumptions is a prerequisite to analysis of further impacts on rural people and communities, regional economies, agriculture, land, or water. For example, given any projected pattern of coal activity, the methodologies being developed by EDD under this project can be applied to estimate community impacts and flows of State revenues from taxation of mining. (Ref. 1)

Methodology

As an integrating mechanism we are using a linear programming model. Although a linear programming model calculates optimal or least-cost solutions to resource allocation problems, we are not in any way attempting to find the optimum pattern of coal development. We want to compare many alternative future coal development patterns, each the product of a special set of policies, in some instances expressed as model constraints. The comparisons should be done under consistent ground rules that the solution is always least-cost. In effect, the optimizing model specifies that the economy is as efficient as possible in carrying out whatever set of policies is being analyzed, given the specified constraints which are not policy-related.

After trial runs of the model to work out technicalities, including a run with constraints and policy factors to duplicate actual coal mining, transportation and usage for 1975, a run will then be made to determine a hypothetical 1975 least cost solution. These runs will provide both an actual and a least cost base for 1975, against which least cost projections for future years can be measured. In other words, each new projection or new analysis of a set of policy alternatives and economic constraints involves a new run of the model.

The model for the interregional analysis of coal development is being constructed incrementally beginning with the coal production areas of the Northern Great Plains (NGP). The model for the NGP will be a prototype for the models to follow. The NGP will be modeled in a fashion similar to the way in which the national situation will be modeled at the completion of the project time frame. Data are currently being placed in the NGP model. The Rocky Mountain States situation will be modeled next, and data are being assembled.

Then the Northern Great Plains and Rocky Mountain States will be combined into a Western States model. Concurrently, data are being obtained for the Interior region, the Appalachian region, and the Gulf region, and models for these will also be constructed. Each of these models can be used individually or in combination with the models for other regions to form the National Interregional Coal Analysis Model. Scenarios will be developed which are region-specific or national in scope and the locational, quantity, and cost impacts of these scenarios will be evaluated using the models.

Data Requirements

The data requirements for an analysis of this magnitude are extensive. Information must be gathered for all of the various components of the model for each Coal Production Area (CPA) of the United States. 1/ We are first developing the coal supply information necessary for each region. The CPA's have been defined and resource, reserve, and production information for each of these areas is being collected. (Ref. 2) The effort is complete for the NGP and the Mountain regions, and is progressing rapidly for the Interior and Appalachian regions. Land use information for each of these regions, including agricultural aspects, is also supplied.

Many of the inputs necessary for the model are being generated under contract at Colorado State, North Dakota State, and West Virginia Universities. Coefficients and other information for the water situation in the Western States are being developed.

Data on mined-land reclamation for the Western States, such as costs, are also being obtained. National-regional coal demand estimates are being generated. Existing econometric studies will be utilized to provide region-specific demand estimates.

During the past several months, we have placed primary emphasis on completing and building a data base for specific mines in the Northern Great Plains and for power plants nationwide. The mine information for the Northern Great Plains is essentially complete with just a few minor corrections to be made in the data base. The data for the electrical generating plants in the United States have given us substantial problems. These problems are essentially solved now, however.

We have data on 291 power generating plants of 100 megawatt capacity or larger; these 291 plants account for about 97 percent of coal-fired electrical generation in the U.S. We have been working with FPC Form 423 data for 1975 on the kind and source of coal and combustion results for each of these plants and will incorporate it into our electrical generation data bank. We have information from Research Triangle Park, EPA, and are incorporating that into the data bank. The FPC Form 67 data on air and water quality for 1975 will not be available until late this summer but will be incorporated in the data base at that time.

North Dakota State University is specifying transportation options for western coal, narrowing the possible options for movement of western coal to Interior and Eastern markets. They are currently developing transportation cost and capacity coefficients. They are looking at railroad, barge, pipeline, and transmission alternatives and will select an efficient subset of all possible modes. They will optimize in a very limited sense, that is, examining all possible alternatives judgementally and selecting the three or four which seem to be the most feasible. Then these three or four will be entered into our model and our model will optimize among them. Otherwise, the inclusion of all possible transportation alternatives in our model would create a data overflow problem. As it is, the linear program will be manipulating about 90,000 bits of data.

Improvements Over Other Models

Since there have been other interregional coal analysis models developed at various sources, one might logically ask what another model of this type being developed by USDA can add to the literature already available. We are attempting to build into our model a level of detail adequate to answer the impact questions being asked by specific rural communities, by environmentalists, Indian tribes, farmers, ranchers, and local, State, and national policymakers. To do this we are looking at the relatively small Coal Production Areas as described above and defining reserves and production capabilities for these Areas. We are aggregating individual mine data to the Coal Production Area level.

At the other end of the coal supply trajectory, as noted, we are looking at coal demand in individual power plants 100 megawatts in size or larger. Looking at the supply-demand situation at this level of disaggregation is a clear improvement over previous models of this type. This level of disaggregation is virtually necessary to answer the local level impact questions being asked within USDA and by EPA.

Scenarios To Be Examined

Policy scenarios to be formulated and evaluated using the Interregional Coal Analysis Model may be region-specific or national in scope. Virtually every aspect of coal supply or electrical generation can be altered through the assumptions of a long-run scenario.

Specifically, each scenario to be developed

1/ Coal Production Areas are special sub-regions defined for this project and consist of one or several counties. For example, we define that there are 13 Coal Production Areas in the NGP.

will include a different combination of several policy and economic factors. Some of these factors will affect the projected level of total coal demand, or the projected regional pattern of demand. Other factors will be constraints in the linear program as it determines the locational pattern of coal supply. Among the policy factors may be federal switching-to-coal orders for both electrical utilities and industrial coal burning facilities, or federal loan guarantees for coal gasification and liquefaction plants. New sulfur dioxide emission standards, non-degradation rules, and State air-quality implementation plans may be analyzed in another scenario under certain water supply and land reclamation constraints. In addition, State, local and national taxation policies could be evaluated. Transportation policies and constraints may be assessed in another scenario, or combined with some of the above.

Coordination with Other Assessment Work

This regional-national analysis is being coordinated with the other work being conducted under EPA's integrated assessment program. As already noted, ERS is also making an assessment of rural community impacts resulting from coal development. That work includes alternatives on coal taxation and other State and local policies. (Ref. 4)

In addition, we are coordinating our work with integrated assessment work being done outside the USDA at the University of Oklahoma. Several conversations and/or meetings have been held with the Oklahoma team to ensure that the data which they are generating and the scenarios which they are evaluating will be compatible with ERS work. In a similar vein, we are coordinating our efforts with the work being done at the Denver Research Institute (DRI) on communities. The work being done at DRI is compatible with work being done by ERS. Every effort is being made to avoid duplication of work.

COORDINATION WITH EPA AND USDA PROGRAMS

We hope to remain as flexible as possible concerning the use of this interregional model. We want this model to have continuing utility not only within the USDA but for ongoing EPA programs. During EPA's continuing evaluation of individual electrical generation and industrial coal-using sites, we hope a way can be found to use the outputs of this model in conjunction with other models, such as those of airsheds and pollution sources. The impact of changes in individual regulations or the granting of variances could be evaluated using our model.

Within the USDA, we would hope that this model will be useful for evaluating the impact of mining on the productive capability of agriculture. Various assumptions concerning the desirability of mining on alluvial valley floors or highly productive agricultural land could be evaluated. The impacts of various reclamation control assumptions could also be evaluated. The impact of reclamation practices on the cost of supplying coal to users as well as the impact on agricultural production and the utilization of labor in rural communities could be assessed.

SUMMARY

The project "Economic and Social Consequences of Coal and Oil Shale Development" assesses the effects of alternative public policies toward coal on the future locational patterns of coal mining, transportation, and usage throughout the U.S. and the specific flows of coal involved. Also assessed are the use of land and water and economic activity such as agriculture, as related to coal development patterns.

A large linear programming model using about 90,000 bits of data is the integrating mechanism. Although it is an optimizing model, it does not seek some theoretical "best" pattern of coal development. Rather, the objective is to compare many public policy alternatives toward coal development and usage, given physical and economic constraints. These alternatives are to be compared under common ground rules that the economy is as efficient as possible in carrying out each hypothetical alternative; hence the optimizing model.

Each run of the model will yield a distinctive pattern and level of coal activity by location in some future year for each alternative policy scenario and set of constraints, given some projected level of total demand for coal. Successive model runs under alternative scenarios will yield other patterns. Then, by comparing these different patterns, certain effects can be attributed to a policy alternative.

The Western States regional model will be running in the fall of 1977, with Interior, Appalachian, and Gulf regional models to follow before the national model is put together. Alternative policies to be assessed will concern such variables as sulfur dioxide emission standards, reclamation requirements, and switching-to-coal orders, as well as others.

Through consultation with EPA and other agencies, as well as within USDA, we will assure that alternative policy scenarios to be assessed are as realistic as possible.

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2. Northern Great Plains Resources and Coal Development. Unpublished working paper, April 1977, prepared by Economic Research Service, USDA under interagency agreement with EPA as part of EPA's Energy/Environment R and D Program. Forthcoming as a publication following internal review.

3. Schaub, John R., Joseph R. Barse, and Lloyd D. Bender. "Research Program on the Economic and Social Consequences of Coal and Oil Shale Development," in Health, Environmental Effects, and Control Technology of Energy Use, Proceedings of EPA Conference, 1976, EPA Report 600/7-76-002.

4. Stinson, Thomas F. State Taxation of Mineral Deposits and Production. Prepared under interagency agreement between Economic Research Service, USDA and EPA as part of EPA's Energy/Environment R and D Program. EPA Report 600/7-77-008, January 1977.

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INTEGRATED SYSTEMS SIMULATION OF LOCAL COMMUNITY IMPACTS IN THE NORTHERN GREAT PLAINS

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INTRODUCTION

This report is a summary of the purpose, objectives, and accomplishments of the energy impact research of the Economic Development Division, Economic Research Service, of the U.S. Department of Agriculture. 1/ The immediate application is to local community impacts of coal development within the Northern Great Plains.

The on-going research of the EDD, ERS, USDA concerns the changing economic and social conditions in the nonmetropolitan areas of the Nation. This project complements that effort. The research and its application is enhanced by the cooperative research agreements that EDD, ERS, USDA has maintained with Montana State University, North Dakota State University, and the University of Minnesota as a part of its continuing program.

Purpose

The specific purpose of the project at this stage is to develop methodologies for estimating the components of local impacts stemming from resource development. The impact components which are most important at the local level are employment, population, wage levels, tax revenues, and government expenditures. Each of these elements is a part of an integrated impact simulation system. The research strategy serves several functions. First, the methodologies for estimating each impact element can be used by others for impact and policy analyses since the components can be estimated independently. Second, others can evaluate and improve the methodology research due to the early interaction with the technical research community. Third, the fundamental function is to improve on the current state-of-the-art of impact estimation.

State of the Arts

A frequent criticism of impact analyses is that estimating techniques and integrative approaches are not refined. 2/ Current estimating procedures frequently involve unrealistic assumptions with respect to multipliers, migration and labor force responses, and tax analyses. Employment multipliers often are assumed to be the same for every geographic site and for every industry as well; that is, it makes no difference whether a new industry is located close to a metropolitan area or in an isolated area where services are not developed.

Interrelationships between the labor force required, migration, and wage levels seldom are considered. The typical assumption is that an unlimited supply of labor is available through migration at prevailing wage rates.

Finally, the cost of local government services are calculated without regard for the anticipated degree of local wage inflation despite the observed experience in boom towns.

The caveat is simply that methodologies for estimating these components of an impact at a local level are inadequate.

COMPONENTS AND INTERRELATIONSHIPS OF A COMMUNITY IMPACT MODEL

The major components of the integrated community impact simulation system are presented in **Figure 1.** The model takes as given the size, type, and location of a coal mine or conversion plant. The increase in local employment is calculated once the employment requirements of the energy project are known.

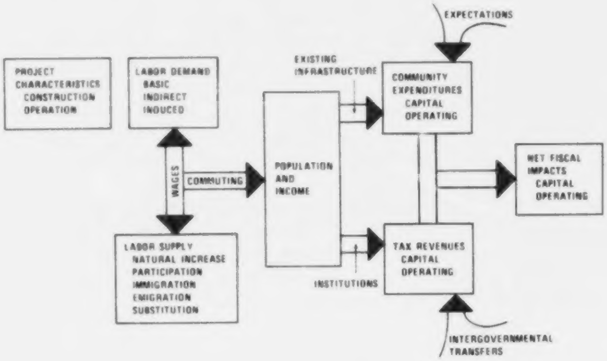
EXPECTATIONS
PROJECT CHARACTERISTICS CONSTRUCTION OPERATION
LABOR DEMAND BASIC INDIRECT INDUCED
EXISTING INFRASTRUCTURE
COMMUNITY EXPENDITURES CAPITAL OPERATING
WAGES
COMMUTING
POPULATION AND INCOME
NET FISCAL IMPACTS CAPITAL OPERATING
LABOR SUPPLY NATURAL INCREASE PARTICIPATION IMMIGRATION EMIGRATION SUBSTITUTION
TAX REVENUES CAPITAL OPERATING
INSTITUTIONS
INTERGOVERNMENTAL TRANSFERS

Figure 1. Relations among elements of local impacts of coal mining development.

1/ Environmental Protection Agency, interagency agreement EPA-IAG-D6-E766, Social and Economic Consequences of Coal and Oil Shale Development, initiated late 1975. Another part within the ERS is performed by the Natural Resource Economics Division.

2/ Office of Technology Assessment, "A Review of the U.S. Environmental Protection Agency Environmental Research Outlook FY 1976 through FY 1980," pt. VI. Socio-economic Research, United States Congress, p. 98.

A larger labor supply is required in the community. This is accomplished in the system through changes in migration streams into and out of the area. Wages and other local economic conditions are the mediating influences between labor demand and supply. Wages are bid up. The results of these interrelationships are a larger population and higher incomes after development of a project. Thus, the dollar cost of community services rises with population increases and local wage inflation.

The other side of the picture is that local tax revenues are affected little by changes in income except through real property taxes. Revenues from severance, sales, and income taxes usually go to the state. Some are returned to the locality as state aids. But state aids to local governments vary greatly from state to state.

RESEARCH ACCOMPLISHMENTS

The first phase of research has been completed on estimating employment, migration, and wage interrelationships and state and local government revenue flows. The criteria for judging the results are twofold. First, the results are tests of theoretical relationships; that is, whether the relationships are exhibited in the data. Second, the results are to be predictive. Theoretically sound relationships may be validated with statistical results but at the same time an acceptable confidence interval for a predicted value may not have been achieved. Accomplishments at this time are expressed in terms of the first criterion.

Estimating Employment

Ancillary employment in a county is a function of the type and location of an industry, the size of activities in neighboring counties, and the location of the county in economic space (4, 6, 7). 3/ Each industry will have a different multiplier due to both the quantity of goods and services used in production and whether the services are purchased (and competitively furnished) locally. Furthermore, the multiplier varies with the distance the county is from a trade center (Table 1). The local multiplier will be smaller if goods and services are supplied by expansion of an existing regional trade center, depending upon how far away it is.

A spillover to neighboring towns which are not trade centers also is demonstrated by the statistical results. (These are shown by each industry and town size ratio interaction in appendix Table 2.) The amount of the spillover from a county of direct impact to a neighboring county is a function of the relative size of towns in each county and size of the basic industry. Trade will tend to move toward large adjoining towns. A small neighboring town will be a very small recipient of any spillover.

TABLE 1. EMPLOYMENT MULTIPLIERS BY INDUSTRY AND DISTANCE TO A MAJOR TRADE CENTER, COUNTIES IN THE NORTHERN GREAT PLAINS, 1970.

Miles distance	Industry		
	Agriculture	Mining	Manufacturing
0	.48	2.58	3.61
50	.77	1.14	3.10
100	.91	.79	3.22
Values at means 1/	.88	.79	3.11
Maximum (minimum) value	.93	(.77)	3.07
Miles	123.62	90.96	65.08

1/ Average distance is 83.4. Average employment is 744 for agriculture, 62 for mining, and 212 for manufacturing in the 181 nonmetropolitan Plains counties.

This part of the model predicts the service employment derived from an increase in basic employment. Basic industry sectors are those which generate a flow of funds into a community. These are defined as agriculture, mining, manufacturing, and a calculated portion of transportation. Ancillary or service employment is that portion which services the basic industry and individual consumers. Each basic sector employment is entered in the model as a cross product relationship with distance in a quadratic form. Other variables in the equation are intended to measure local anomalies in the economic base such as the presence of a college, institution, or concentrations of government employment. Finally, the variables representing basic activities in adjacent counties and the expected flow of trade are represented as interactive cross products.

The data are cross section employment by sector from the 1970 census of population. The technique is multiple regression analysis with results shown in Table 2. The problems associated with predicting from cross section analyses are treated in the next phase of research. Techniques allowing the use of combined cross section and temporal data for small areas are being tested (6, 7).

Migration and Wage Interrelationships

The direct and induced employment demands of an energy project in a rural area can be greater than that supplied by the indigenous labor force. Migration streams must be altered in order to fulfill the labor demand of employers. It is realistic that net migration of the magnitude needed is unlikely to take place without economic inducements. Furthermore, the responsiveness of migration streams depends on the source of in-migrants and destination of out-migrants (Figure 2). Less financial inducement likely is required to induce people to move within the region. Migration is affected by site

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3/ Bracketed numbers refer to publications and studies in progress.

TABLE 2. ESTIMATED COEFFICIENTS AND STATISTICS OF THE ECONOMIC BASE MODEL FOR THE NORTHERN GREAT PLAINS REGION, 1970

Variables and classifications	Regression coefficient	Standard error	F 3/ statistic
Primary basic sectors and distance to a major trade center.			
Agricultural employment & distance			
AGR	0.48387	0.25335	3.6476
AGRDIS	0.00717	0.00398	3.2415
AGRDISQ	-0.00003	0.00002	3.7740
Mining employment & distance			
MIN	2.57544**	0.92924	7.6814
MINDIS	-0.03966*	0.01992	3.9659
MINDISQ	0.00022*	0.00011	4.0987
Manufacturing employment & distance			
MAN	3.60842**	0.29988	144.7927
MANDIS	-0.01666*	0.00787	4.4730
MANDISQ	0.00013	0.00006	3.8341
Transportation employment & dist. 1/			
TRN	5.69776**	0.58195	95.8595
TRNDIS	-0.03587	0.03569	1.0099
TRNDISQ	-0.00032	0.00032	0.9864
Scale of basic activities in adj./co's			
ADJ AGR & town sizes 2/	0.27981**	0.03794	54.3831
ADJ MIN & town sizes 2/	0.38374**	0.07739	24.5810
ADJ MAN & town sizes 2/	0.09199	0.10233	0.8080
Other variables			
Income	0.09667	0.05903	2.6820
Institutional population	1.53791**	0.30266	25.8191
Students in group quarters	1.08617**	0.16499	43.3387
Local government 1/	1.24263	1.48242	0.7027
Constant	-530.638		
Statistics			
R^2		.9652	
Standard error		728.6383	
Observations		181	
F statistic		235.0230	

1/ Calculated as amounts above regional proportions.

2/ (X_{ik}) (T/T_j) where k is the adjacent county with the largest employment in i, T is the largest town in the observation county, and T_j is the largest town in any adjacent county j.

3/ The F statistic is produced as part of the SPSS computer package. Significance represented by * for 0.95 and ** for 0.99 confidence levels.

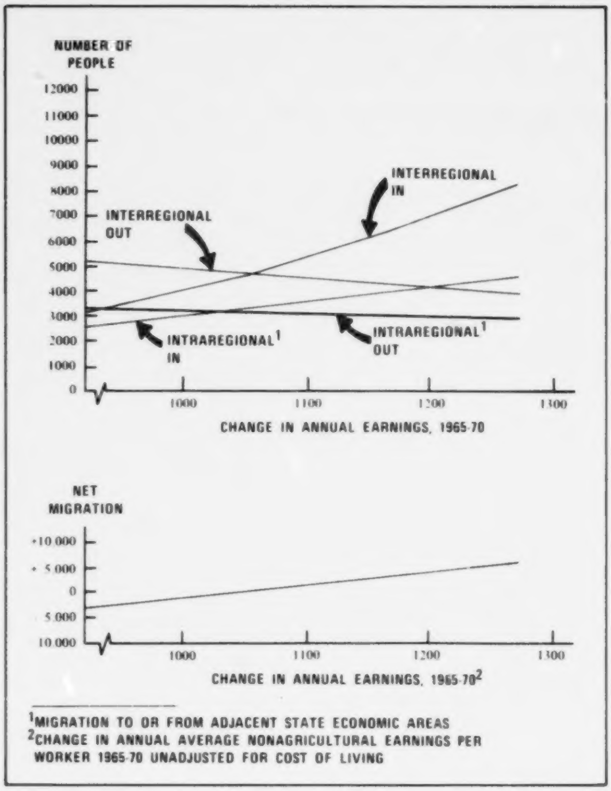

Figure 2. Migration responses to earnings changes Montana SEA-4, 1965-70.

amenities (including human capital values) which are not lost in a short distance move.

The heart of the labor supply component is a set of simultaneous relationships which demonstrate that economic incentives (notably wages) alter migration streams. Migration is the major source of population change in rapid growth areas. Out-migration declines and in-migration increases in order to produce a population change as wages are bid up. Population and wage levels are the major determinants of the cost of local government services.

Three migration equations are estimated (5). One describes movements from and another movements to State Economic Areas (SEA's) of the Northern Great Plains and the states in the rest of the nation. The third equation considers all streams among the SEA's of the Northern Great Plains. A migration stream is the number of people moving from place i to place j from 1965 to 1970, and is the dependent variable. By using gross migration streams as the dependent variable, economic conditions at origins and destinations can be isolated.

The models are a simultaneous system since migration can be expected to influence wage rates (by altering the supply of labor) as well as be influenced by wage rates. It is for this reason that two-stage least squares techniques were used to estimate the parameters of the models. The results are presented in Table 3. Three categories of variables are shown: control variables, and economic conditions both at the origin and the destination. The coefficients reflect the fact that all variables are transformed into logs prior to estimation, and are interpreted as elasticities.

This research demonstrates statistically significant relationships between migration and local economic conditions. The results are not accurate enough to forecast migration to rapid growth energy towns. The population and wage components are so fundamental to local impact analyses that additional basic research is appropriate. The second phase of research will consist of labor market modelling using annual data series. It will concentrate upon labor's responses to wages in local labor markets but will abstract completely from the source of the labor.

Local and State Tax Revenues

The state and local revenue systems have been computerized for Montana, Wyoming, North Dakota, and South Dakota in a routine called ENGYTX. Revenues and intergovernmental transfers are calculated by source, type of tax, and level and type of government in ten summary tables (8). Taxes can be derived for three different sized strip mines and a thermal conversion plant during a production year for the mine and its primary employees. ENGYTX requires that the type of project, its site, and millage rates be provided. In addition, specific information such as the number of operating employees, construction and operation costs, and the income distribution of employees is needed.

The value of ENGYTX in the simulation model is that revenue flows to local governments are specified as a source of funds for expansion and operation. These can be compared to expenditure requirements and budgeted needs. But ENGYTX can be used by itself or by others as a source of information for environmental impact statements, evaluations of the complete tax system and changes in it, and policy analyses of both firms and local governments. 4/

A summary of results of ENGYTX is presented in Table 4. The data illustrate the type of detail gained, the complexity of each tax structure, and differences in tax systems. An illustration is the support levels for schools. School levies in Wyoming remain in the district while the statewide levy in Montana flows into the state equalization fund once county foundation levels are met. Another example is the fact that much of the local government revenue in North Dakota consists of State aid. The effect of a change in one tax must be evaluated in the context of the whole system due to these complex relationships.

4/ Background information for ENGYTX and is contained in (3, 9, 10).

TABLE 3. INTRA- AND INTER-REGIONAL MIGRATION MODELS, 1965-70, NORTHERN GREAT PLAINS STATE ECONOMIC AREAS 1/

Items and independent variables	Exp. sign	Intraregional model	Interregional models	
			In-migration	**Out-migration**
		------Coefficients 2/------		
Controls				
Population 3/	+	1.22	1.05	1.66
Distance, origin to destination	-	-1.46		
Town sizes, destination/origin	+	0.19	0.32	
Median age at origin, 1970	-			-3.89
Distance, largest adj. town/observed 4/	+	0.25	0.94	
Town sizes, largest adj./observed 4/	-	-0.26	-0.32	
Past migrants at destination, 1970	+	0.41	0.66	0.76
Economic conditions at destination				
Employment change, 1965-70	+			0.16
Wage change, 1965-70	+	1.68	3.13	
Wage in 1965	+	3.13	3.70	
Subemployment, 1970	-	-2.03	-1.22	
Economic conditions at origin				
Employment change, 1965-70	-			-0.13
Wage change, 1965-70	-	-0.35	-1.11	-0.87
Subemployment, 1970	+		0.23	0.89
Intercept		-16.17	-24.09	-1.31

1/ Results are from 2SLS regression. Models correspond to those reported as final models in appendix tables 6, 9, and 12.

2/ Coefficients are interpreted elasticities since data are in double logarithmic form.

3/ Reported as at origin for interregional out-migration and intraregional migration, and at destination for the interregional in-migration model.

4/ Reported as ratio of origin town for interregional out-migration and intraregional migration, and at destination town for interegional in-migration model.

A second computer tax model is called MINETX (2). It differs from ENGYTX in several important ways. First, it calculates the taxes that specific mines pay during a production year; that is, the taxes of the firm alone. Second, the program is communicative so that the operator can vary the characteristics of the tax system to discover what difference would be made in the taxes of a firm if laws were changed. Third, MINETX is operational for any state.

A third accomplishment of the tax work is a current summary of minerals tax systems of every major mineral producing state (1). A brief analysis of types of taxes is provided and the highlight of special impact taxes in the Northern Great Plains is included.

Phase two of the revenue and expenditure components of the simulation model involve an extension (a) to a wider geographic coverage, (b) to incorporate the effect of service employees in ENGYTX, and (c) to estimate local government expenditures in relation to population size and wage levels.

PROGRAM DISCUSSION AND CONCLUSIONS

The research is designed to extend the state-of-the-art consistent with a goal of remaining applied. The various components of a simulation model are to be estimated in a straightforward way. The estimation techniques are constrained to use data series which are available nationally and preferably on an annual basis.

Each component of the model is designed to stand alone. This means that the results can be adopted by others quickly, and that no one component will forestall application of other components. The overall model can be expanded or contracted as needed without destroying the key structure. Furthermore, the research of others can be integrated into the procedure.

The general estimating approaches are meant to be exportable to other regions and impacts. Use of secondary data facilitates this goal. Nothing in the estimating techniques restricts them to coal development or the Northern Great Plains.

TABLE 4. EXECUTIVE SUMMARY STATE AND LOCAL REVENUES, ONE PRODUCTION YEAR, 9.2 MTY STRIP MINE AND PRIMARY EMPLOYEES SELECTED SITES, MONTANA, WYOMING, NORTH DAKOTA, AND SOUTH DAKOTA. 1/ 2/

Government and revenue	State			
	Montana	Wyoming	North Dakota	South Dakota
	- dollars per production year -			
State and local revenue, total	11,680,554	3,891,387	5,392,515	867,990
Local government, total	1,170,858	1,890,026	543,947	371,095
School district, total	334,238	1,320,321	226,221	243,709
Tax revenue	144,402	1,299,861	48,349	218,499
State aid	189,836	20,460	178,272	25,210
City, total	52,969	32,192	31,634	17,459
Tax revenue	45,531	7,835	23,317	12,584
State aid	7,438	24,357	8,317	4,875
County, total	783,651	537,513	285,691	109,926
Tax revenue	393,312	456,035	28,073	103,877
State aid	390,339	81,478	257,618	6,049
State government, total	10,509,696	2,001,361	4,848,568	496,896
General fund	5,080,713	1,570,088	1,738,968	496,896
Earmarked 3/ 4/	5,428,983	431,273	3,109,600	---
Direct transfers to govt.'s 5/	(587,613)	(126,295)	(444,208)	(36,134)

1/ Prices, operating costs, and characteristics of this mine are those reflected in the Bureau of Mines Circular 8703. Assessment and millage rates are those of Rosebud, Campbell, Mercer, and Harding counties levied in 1975.

2/ Includes 213 primary mine workers.

3/ Includes state school equalization from state wide levy remaining after county foundation is deducted.

4/ Includes various impact funds not allocated by formula.

5/ Shown as state aid above and not included in state total.

Experimental work such as this frequently raises questions of theory, technique and application which have not been addressed by others. This can be invaluable to an on-going research program. The questions which need additional research are highlighted and the expertise and experience is maintained within the project.

PUBLICATIONS

1. Stinson, Thomas F., "State Taxation of Mineral Deposits and Production," EDD, ERS, USDA. Working Paper No. 7606, Dec. 1976, and OEMI, EPA publication No. 60017-77-008, Jan. 1977.
   Summarizes mineral tax laws of all major producing states, gives an overview of special laws of Northern Great Plains States, and provides a brief analysis of all mineral tax laws.

2. Stinson, Thomas F., "An Introduction to MINETX," EDD, ERS, USDA. Working Paper No. 7704, March 1977 in cooperation with OEMI, EPA.
   MINETX is a computer - assisted aid for the simulation of the effects of any state tax system on the taxes paid by coal mining companies. A brief description of the computer program and examples of operating commands and output are given.

3. Voelker, Stanley W., Fred R. Taylor and Thomas K. Ostenson, "The Taxation and Revenue System of State and Local Governments in North Dakota," North Dakota State University Agricultural Economics Report No. 117, Dec. 1976 in cooperation with EDD, ERS, USDA and OEMI, EPA.
   Describes in detail the state and local tax system of North Dakota with special emphasis on coal mining and processing.

STUDIES IN PROCESS

4. Bender, Lloyd D., George Temple, Bernard Ries,

"Estimating Employment Multipliers for the Northern Great Plains," EDD, ERS, USDA in cooperation with OEMI, EPA.

Uses cross section census data in a disaggregated industry employment estimating model for the Northern Great Plains. Multipliers vary by industry, the location, and the activities in economic space.

5. Bender, Lloyd D., George Temple, and David O'Meara, "Responsiveness of Migration Streams to Local Economic Conditions in the Northern Great Plains," EDD, ERS, USDA in cooperation with OEMI, EPA.

   Reports on econometric analysis of migration to and from State Economic Areas in the Northern Great Plains in a simultaneous system of equations with wages and other local economic conditions. Shows 1965-70 migration streams in NGP SEA's to be significantly responsive to wages but different for short and long distances.

6. Conopask, Jeff V., "Estimating Energy Employment Multipliers Using Temporal Cross Section Data," EDD, ERS, USDA in cooperation with OEMI, EPA.

   Uses advanced econometric techniques to test an employment multiplier model of NGP counties for time lags in the adjustment process. Uses annual Bureau of Economic Analysis employment series for basic sectors across selected NGP coal impact counties 1970-74. A one-year adjustment lag to mining employment is statistically significant.

7. Conopask, Jeff V., "A Time Series-Cross Section Approach to Secondary Employment Estimation," EDD, ERS, USDA in cooperation with OEMI, EPA.

   A journal article demonstrating the reasons for and efficacy of using selected econometric techniques in analyzing cross-section time-series data as applied to employment multipliers in 15 NGP coal producing counties 1970-74.

8. Stinson, Thomas F., and Stanley W. Voelker, "State and Local Revenue Flows from Coal Mines and Conversion Facilities in the NGP," EDD, ERS, USDA in cooperation with OEMI, EPA.

   Demonstrates differences in tax revenues, intergovernmental transfers and disposition of revenue for state and local governments for mines in Montana, Wyoming, North Dakota, and South Dakota.

9. Thompson, Layton, "The Taxation and Revenue System of State and Local Governments in Montana," EDD, ERS, USDA in cooperation with OEMI, EPA and Montana State University.

   Describes in detail the state and local tax system of Montana with special emphasis on coal mining and processing.

10. Thompson, Layton, "The Taxation and Revenue System of State and Local Governments in Wyoming," EDD, ERS, USDA in cooperation with OEMI, EPA and Montana State University.

    Describes in detail the state and local tax system of Wyoming with special emphasis on coal mining and processing.

11. Myers, Paul A., Jeff V. Conopask and Fred K. Hines, "A Social and Economic Profile of 47 Coal Impact Counties in the Northern Great Plains," EDD, ERS, USDA in cooperation with OEMI, EPA.

    Describes baseline population, employment, settlement patterns and social conditions which will influence the impact of coal development in 47 counties in the NGP. Data are from census of population and Bureau of Economic Analysis.

METHODOLOGY FOR THE ANALYSIS OF THE IMPACTS OF ELECTRIC POWER PRODUCTION IN THE WEST

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INTRODUCTION

Overview

During the year 1976, a multi-disciplinary team of scientists was organized to investigate the impacts of electric power production in the West. This team has developed and exercised a quantitative mathematical model for simulating the development of additional electrical power capacity in the western states and estimating the associated primary and secondary costs. This paper describes in summary form the organization of the project, its accomplishments so far, and its future course.

Purpose

The general purpose of the project is to develop a cost-analysis methodology for electric-power capacity that is suited to the unique characteristics of the coal- and uranium-rich, but sparsely populated, pristine, and arid West. (See Table 1.)

TABLE 1. ROCKY MOUNTAIN STATES

FEW PEOPLE –
4% POPULATION VS 26% LAND AREA

CLEAN AIR & SCENIC –
75 MILE VISIBILITY (SW) &
40-50% OF NATIONAL PARKS AND MONUMENTS

ARID –
15 INCHES RAINFALL (SW)
VS
50 INCHES RAINFALL (EAST)

Plan of the First Year's Effort

During the first year of the project, the team developed or adapted five submodels for the simulation of power development impacts on the West and its inhabitants and four submodels for evaluating the cost of these effects. The interconnections among these submodels are shown in Fig. 1 and Table 2.

For definition, we based the first year's calculation on the expansion plan proposed by the electric utilities belonging to the Western Systems Coordinating Council (WSCC). This plan describes the locations, completion dates, fuel types, and sizes of power plants to be completed in the WSCC service area by 1985. [1]

The members of the WSCC propose to generate electricity from a variety of sources, but we have limited the study to nuclear plants and plants fired by coal, oil, or gas. The locations of the larger plants to be operating in the region by 1985 are shown in Fig. 2. In this figure, the letters designate the types of plants, and the sizes of the letters correspond to the sizes of the plants (small, 500-999 MWe; medium, 1000-1999 MWe; and large, 2000 MWe and larger). The squares in the Los Angeles and San Francisco regions indicate oil-fired plants too densely located to represent individually.

Our selection of the utilities' expansion plan does not mean that we consider their projections to be the best prediction of future capacity. Utilities may err in their forecasts of growth in demand or in their assessments of community acceptance of their plants. Indeed, one of the most controversial plants shown in Fig. 2--the Kaiparowits plant in southern Utah--has already been cancelled. To emphasize the view that the WSCC report describes but one set of possible input conditions, we have not removed the Kaiparowits plant from the initial scenario.

Project Team

The team, assembled to accomplish the broad purposes discussed above, consists of a professional staff with training in statistics, economics, law, engineering, systems analysis, sociology, and anthropology. The project is coordinated by staff members from the Los Alamos Scientific Laboratory (LASL) in Los Alamos, New Mexico. Individual projects are being conducted by analysts from LASL as well as from Battelle Pacific Northwest Laboratory (PNL), Hanford, Washington; the University of Southern California (USC), Los Angeles, California; Northern Arizona University, Flagstaff, Arizona; and the University of Alberta, Edmonton, Canada. A list of separate reports being prepared by members of the team is given in Table 3.

TECHNICAL DISCUSSION

Illustrative Results

We are now able to present preliminary estimates of the major internal and external costs of building and operating the plants proposed in the WSCC plan. In exercising the submodels shown in Fig. 1, two impacts were found to yield large dollar costs:

1. the boom town impact (manifested in part in lowered productivity of the construction work force), and
2. the impact of reduced atmospheric visibility.

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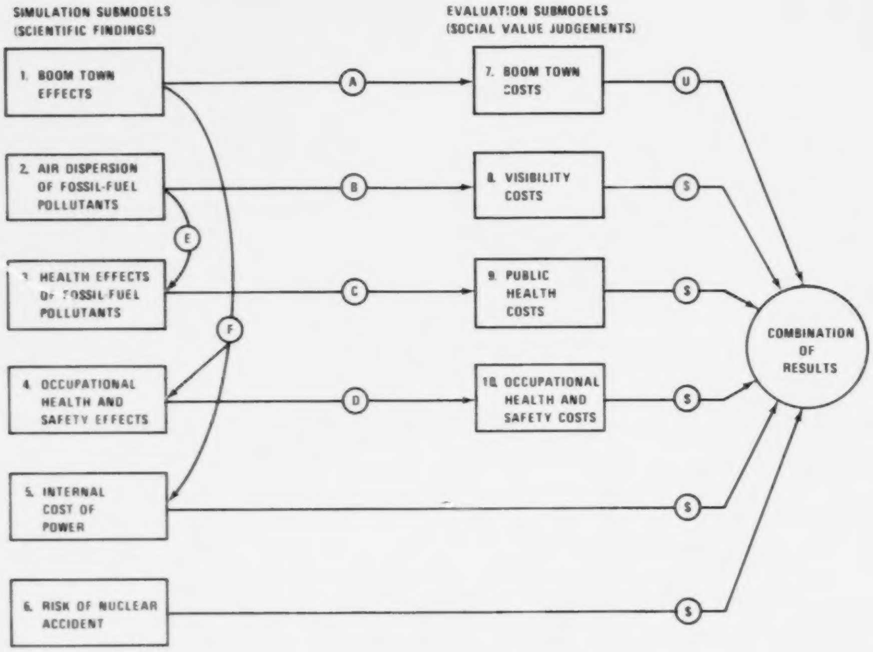
SIMULATION SUBMODELS (SCIENTIFIC FINDINGS)
EVALUATION SUBMODELS (SOCIAL VALUE JUDGEMENTS)
1. BOOM TOWN EFFECTS
2. AIR DISPERSION OF FOSSIL-FUEL POLLUTANTS
3. HEALTH EFFECTS OF FOSSIL-FUEL POLLUTANTS
4. OCCUPATIONAL HEALTH AND SAFETY EFFECTS
5. INTERNAL COST OF POWER
6. RISK OF NUCLEAR ACCIDENT
7. BOOM TOWN COSTS
8. VISIBILITY COSTS
9. PUBLIC HEALTH COSTS
10. OCCUPATIONAL HEALTH AND SAFETY COSTS
COMBINATION OF RESULTS
A
B
C
D
E
F
U
$
$
$
$
$

Figure 1.

Interconnections among submodels.

TABLE 2.

INFORMATION FLOW AMONG SUBMODELS

Symbol in Fig. 1	Description of Information
A	Shortages and surpluses of public and private services shown in Table V.
B	Ambient concentration of total suspended particulates (TSP) and SO_2. (Could not be used in initial effort; total TSP emissions were used instead.)
C	Geographic distribution of the change in age-specific mortality, changes in expectation in life, and the changes in morbidity.
D	Number of man days lost and number of fatalities due to accidents during construction and operation.
E	Geographic distribution of the average annual ambient concentration of SO_2 and TSP about the fossil fuel plants.
F	Decline in the productivity of construction workers at the peak of the boom due to adverse boom town conditions.
$	Final outputs are given in dollars in the initial calculation.
U	Multi-attribute utility measurement (MAUM) has been used to evaluate alternative boom town scenarios. MAUM output is expressed in utility units (utils), which are not directly comparable to dollars.

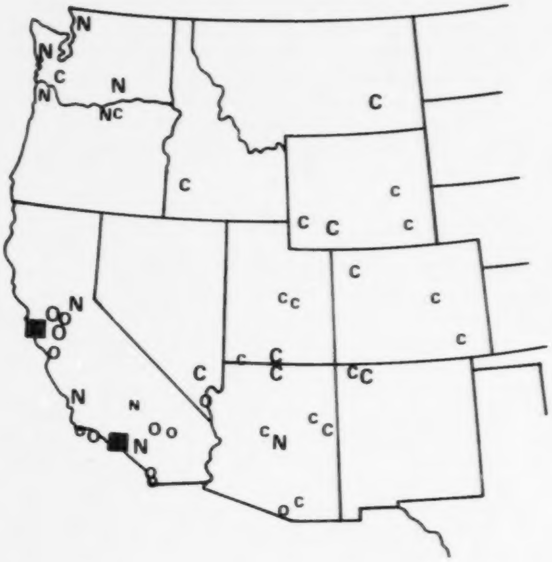

Figure 2. WSCC plant sizes, types, and locations planned for 1985.

N – NUCLEAR
C – COAL
O – OIL

SIZE OF LETTERS N, C, O INDICATES SIZE OF PLANTS.

TABLE 3.

ADDITIONAL REPORTS

1. Andrew Ford, Ed., "Methodology for the Analysis of the Impacts of Electric Power Production in the West: First Annual Report," LASL. (Documentation of model used in the first year.)
2. Lee Erickson, "An Approach to Valuing Visual Pollution From Western Electricity Production," BNWL-2103 (Feb 1977). (Discussion of visibility costs component.)
3. Andrew Ford, "Summary Description of the BOOM1 Model," LASL report LA-6424-MS (June 1976). (Short report on the boom town simulation model.)
4. Andrew Ford, "User's Guide to the BOOM1 Model," LASL report LA-6396-MS (June 1976). (Detailed documentation of the boom town simulation model.)
5. John Wood, "Mobility Plans of Newcomer Construction Workers in Boom Towns: The Case of Rock Springs, Wyoming," Northern Arizona University. (Statistical analysis of the Construction Worker Profile data on Rock Springs, Wyoming.)
6. Steven Schulte, "Power Plant Construction--Productivity and Construction Duration," PN[illegible]. (Results of interviews with construction supervisors on the boom town problem.)
7. Peter Gardiner and Andrew Ford, "Which Run Is Best, And Who Says So?," USC and LASL preprint, submitted to Management Science. (Discussion of the merger of dynamic simulation modeling and multi-attribute utility measurement, with case-study experience.)

Figure 3 shows an example of these and other cost estimates for the coal-fired power plant to be located in the northwest corner of Colorado near the small town of Craig. This plant will generate 1070 MW of power when it is completed in 1982. Since Fig. 3 displays costs which differ by two orders of magnitude, the costs are plotted on a logarithmic scale. The illustrative cost estimates shown in Fig. 3 were obtained as follows:

Capital Cost. The estimate of $370 million is based on a calculated unit cost of $343 per kilowatt of capacity. This estimate includes the cost of SO_2 removal equipment and is based on a 7% annual rate of inflation in the cost of labor and materials. If more recent information on labor and materials costs were used, the estimate would be significantly higher than $343 per kilowatt.

Boom Town Cost. The $100 million cost in Fig. 3 is an estimate of the cost overrun that could occur at the Craig plant due to adverse boom town conditions. This estimate is based on a projection that construction worker productivity could decline by as much as 65% at the peak of the boom in the small town of Craig if preventative action were not taken to avoid the shortages of public and private services that can occur under conditions of rapid population growth. The boom town simulation model (submodel 1 in Fig. 1) is used to make the projection of construction worker productivity during the construction interval. The key assumptions leading to such a large estimate of productivity decline are described in Reports 1, 3, and 4 of Table 3.

In addition to projecting the change in construction worker productivity, the boom town simulation model projects changes in a variety of other variables of concern to local citizens. These include changes in the local tax burden, shortages and surpluses of housing, public facilities, and retail and service facilities, and the number of "newcomers" in the community. Assigning a dollar cost to the changes in these variables proved extremely difficult. Thus, the team turned to an alternative technique for evaluation called Multi-Attribute Utility Measurement (MAUM). The use of a MAUM evaluation model coupled with the boom town simulation model to evaluate alternative boom town conditions is described in detail in Report 7 of Table 3.

Visibility Cost. The visibility submodel is based on the work of Randall et al. [2], who used a specially designed bidding game to determine how much local residents and visiting recreationists would be willing to pay for partial and full abatement of visible particulate emissions from the Four Corners power plant near Farmington, New Mexico. When the Randall results are applied to the air quality control region of northwest Colorado, one obtains a total cost of $6.6 million over the entire life of the plant. About 70% of this total, undiscounted cost is attributed to the recreational visitors to northwest Colorado. Specific details on the visibility calculations are provided in Reports 1 and 2 of Table 3.

Occupational Safety Cost. We project a total undiscounted cost of $.9 million due to fatal and non-fatal accidents occurring during the construction and operation of the Craig power plant. The cost per man-day lost has been assumed to be $50, with 6000 man-days assumed lost per fatality.

Public Health Cost: The estimate of the public health cost was obtained by performing a series of three calculations. First, a climatological dispersion model developed by the EPA was used to simulate the diffusion of SO_2 and total suspended particulates. The dispersion model employs common

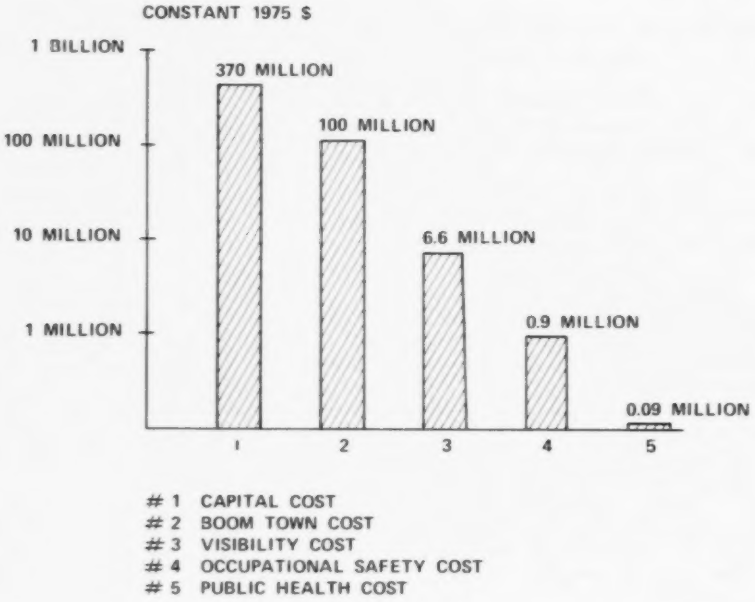

Figure 3.

Preliminary internal and external cost estimates for the Craig plant. With respect to Figure 1, the boom town cost estimate is the difference between the internal cost of power calculated with and without boom town effects reducing construction worker productivity.

assumptions about the physical characteristics of the plant (such as stack height and exit velocity) and ignores the terrain of the surrounding area. Second, the increase in the average annual concentration of the two pollutants in each of the cells surrounding the plant are used to calculate changes in mortality and morbidity of the exposed population. Morality is measured in terms of the reduction in life expectancy; morbidity is described by the shift in the distribution of population health status (with health status characterized on a continuum running from satisfactory to hospitalized).

The final calculation is performed in the public health costs submodel (No. 9 in Fig. 1) which assumes a fixed cost of $50 per day of reduced life expectancy for mortality costs. Morbidity costs consist of direct costs (medical, pharmaceutical, and hospitalization) and indirect costs (productivity losses). These costs are estimated across the spectrum of health status and are summed with weights that describe the change in health status of the population subjected to changes in annual average pollution levels.

As Fig. 3 indicates, the final result of performing this set of three calculations for the Craig plant is a total, undiscounted cost of only $90,000 over the entire life of the power plant.

Submodel Synopsis

Table 4 provides a synopsis of the submodels used in the first year's calculation. The first column of the table indicates those "new" submodels that were developed by the project team during the

TABLE 4. SUBMODEL SYNOPSIS

SUBMODEL	TYPE	STRONG POINTS	WEAK POINTS
Boom Town Effects (BTE) (new)	Dynamic simulation model, coupled feedback loops with nonlinearities and delays	Socio-economic mechanisms are visible. Model is well suited for testing alternative policies.	Ignores certain important factors such as energy development other than power plants.
Air Dispersion of Fossil-Fuel Pollutants (old)	Expected-value, static flow model; linear in emissions	Model is well tested and documented with visible representation of physical and chemical processes.	Very sensitive to site characteristics. Needs better meteorological data.
Health Effects and Costs of Fossil-Fuel Pollutants (modified)	Analytic, static model; linear in concentration of pollutants	Covers all morbidity and mortality effects in a unified manner - a major advantage	Needs better data and minor analytical improvements.
Occupational Health and Safety Effects and Costs (old)	Algebraic formula, linear in plant size	Clear and simple representation of accidents from construction and operation	Neglects effects of decline in morale (from adverse boom town conditions) which may affect safety
Internal Cost of Power (ICP) (old)	Algebraic, capital cost model; discounted cash flow model of cost of power	Model is well tested and documented with visible representation of important variables.	Not applicable for plants smaller than 500 MW or larger than 1500 MW. Underestimates costs due to obsolete data on labor, materials, and methods.
Risk of Nuclear Accident (modified)	Algebraic, expected value model	Extends the general applicability of the Rasmussen estimates in a simple, straightforward manner.	Wind speeds are not considered and various types of damages are aggregated together.
Boom Town Costs (new)	Construction cost overrun estimated from BTE and ICP. Other effects evaluated with MAUM (multi-attribute utility theory).	Merger of MAUM with dynamic simulation model is a useful advance in methodology.	MAUM evaluation is in units other than the dollars used in other submodels.
Visibility Costs (modified)	Algebraic model; nonlinear in emissions; based on a bidding game	Model extended to a multiplicity of sites in a straightforward manner	Model does not consider background pollution, size distribution of particulate emissions, and differing visual opportunities and socioeconomic conditions.

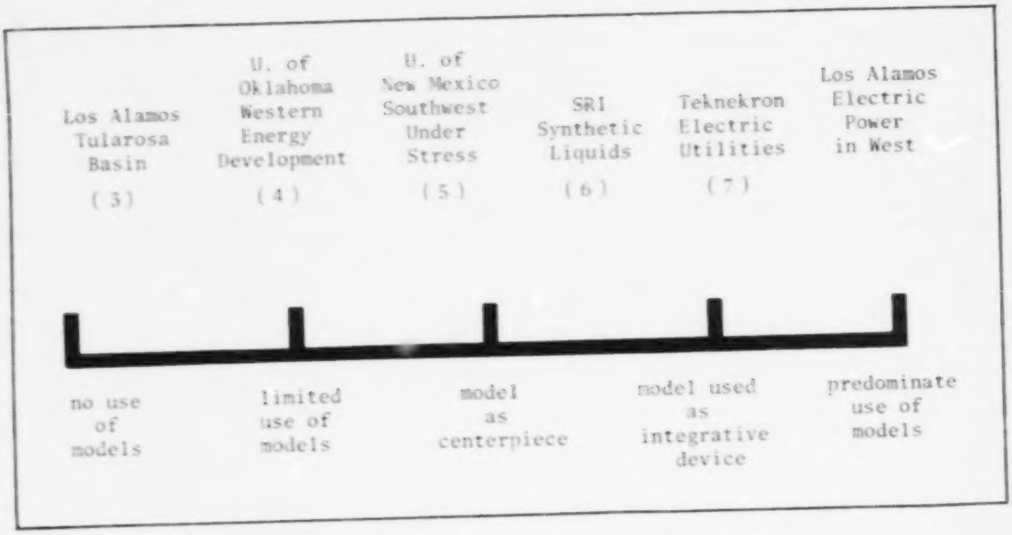
Los Alamos Tularosa Basin
(3)
U. of Oklahoma Western Energy Development
(4)
U. of New Mexico Southwest Under Stress
(5)
SRI Synthetic Liquids
(6)
Teknekron Electric Utilities
(7)
Los Alamos Electric Power in West
no use of models
limited use of models
model as centerpiece
model used as integrative device
predominate use of models

Figure 4.

Emphasis on formal modeling techniques in assessments of energy development.

first year. Subcalculations performed with existing computer codes are designated as "old" submodels in Table 4. The third designation in Table 4, "modified," refers to the submodels that were developed by adapting work done elsewhere to the purposes of the project.

PROGRAM DISCUSSION

Comparison With Related Studies

In Fig. 4 several related studies of energy development are ordered with respect to the emphasis placed on formal modeling techniques. The studies on the left place little emphasis on formal quantitative methods; studies on the right make strong use of such methods. The Los Alamos study of western electricity summarized in this report is located to the far right of the spectrum since we have placed total emphasis on formal methods in pursuit of the goal to develop a methodology for the analysis of the costs of electric power production in the West.

Usefulness of Results

Although the submodels have been constructed to fit together as indicated in Fig. 1, the more immediate usefulness of the research may well be in exercising some of the submodels on their own. The boom town simulation model, for example, can be used to test the effectiveness of a variety of proposals such as loan guarantees and direct grants designed to help towns deal with the "front end" financing problem. At this point in time, five groups outside of Los Alamos have implemented and exercised the boom town model on their own computer system. According to their individual needs, each group is working to expand a particular sector of the model. Analysts at the Commerce Department, for example, are expanding the energy sector to deal with boom town impacts from off-shore energy projects such as deep water ports and oil platforms.

The Multi-Attribute Utility Measurement (MAUM) technique used in the boom town evaluation model also has the potential to be immediately useful in helping decision making groups to resolve value oriented disputes. We have discussed the applicability of the MAUM procedures with decision makers concerned with assorted areas ranging from the selection of a geothermal test site to the evaluation of research proposals. Moreover, the merger of a dynamic simulation model to calculate boom town effects with the MAUM model to evaluate those effects constitutes a novel and useful methodological development. The specific models merged in this project are now being used to resolve some of the key issues concerning boom town problems associated with the development of coal resources in the Rocky Mountain States [8]. Other submodels developed in the first year of the project are finding immediate application as well. The health effects and health costs submodels (numbers 3 and 9 in Fig. 1), for example, are being used as part of the national coal utilization assessment [9].

CONCLUSIONS

Several improvements and expansions are planned for the remainder of the project. Weaknesses in existing submodels are being corrected, and additional submodels are being constructed to cover the impacts from the mining and milling phases of the electric fuel cycle. A water component is being added to represent the effects of diverting water away from western agriculture to cool the electric power plants proposed in the WSCC plan. And finally, a careful study of the relative advantages of using dollar quantification or Multi-Attribute Utility Measurement is being conducted.

After these improvements have been completed, the team will turn to the calculation of the costs associated with a scenario other than the WSCC plan portrayed in Fig. 2.

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5. A Kneese, Status Report, Southwest Region Under Stress, Department of Economics, University of New Mexico, Autumn, 1976.

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7. Teknekron, Inc., An Integrated Technology Assessment of Electric Utility Energy Systems, under preparation on EPA contract No. 68-01-1921.

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9. "Health and Safety Impacts," Chapter 10, Impacts of Coal Development in the Rocky Mountain West, Los Alamos Scientific Laboratory, forthcoming.

health effects

CHAPTER 6

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DEVELOPING SAFE ENERGY TECHNOLOGIES

We are sure that everyone attending this Conference is aware of the tremendous challenge that confronts our country, and indeed all countries, to safely produce the energy necessary for a quality standard of living; energy that is, indeed, vital for our survival. It is obvious that new sources of energy, energy conversion processes, and energy conservation measures must be developed within just a few years. These new technologies will be complex and will inevitably pose potential risks to human health and the environment. The challenge to produce an increasing supply of energy from new sources is considerably complicated by this risk, and dictates that the technology developers and the health scientists work cooperatively to develop energy production facilities which are efficient, safe for the workers, and environmentally acceptable.

For the health scientists, the ultimate objective is to provide the energy scientists with timely information to guide the development of technologies so as to minimize or eliminate potential hazards. To accomplish this it is essential to maintain close cooperative interaction between the engineers and other scientists concerned with energy technology development and the scientists concerned with protecting the public health and welfare. One notable result of the Interagency Energy/Environment Research and Development Program has been the progress made in achieving this interaction. There is still progress to be made, and this type of program accomplishment is difficult to document, but continuing progress in developing such interaction will eventually provide great dividends as our nation proceeds in a major technological assault on the energy problem.

PUBLISHABLE RESULTS SPARCE

When we were reviewing the papers submitted for this session, it became obvious that extensive publishable results in the health effects area are not available at this time.

This statement is not meant to criticize. The situation was to be expected, since several years are usually required to complete health studies. Investigation of the potential health hazards associated with developing and existing energy technologies is a task of enormous scope, requiring coordinated effort beyond the capabilities of any single agency. It has been a time-consuming task to make preliminary assessments, to develop interagency coordination and agreements, to re-examine program priorities and previous commitments, in some cases to rearrange entire research programs, to develop contracts, and to reallocate resources. This extensive preparation was required so that the energy-associated health problems could be researched in a responsive, logical, and fiscally sound manner. Much of the initial years of the Interagency Program was spent in this effort.

DEVELOPING TECHNOLOGIES DIFFICULT TO STUDY

As actual research projects got underway, the life scientists discovered that the study of developing technologies posed considerably more problems than the study of existing industries. The processes within a technology were quite varied, and there was no certainty that the process would maintain the same operational characteristics from pilot plant to commercial plant. There was, and still is, a problem in obtaining suitable test substances. Pilot plants frequently have unpredictable operating schedules, are usually able to achieve steady-state operation only for short durations (and samples taken at other times are practically useless for biological testing), and the populations available for epidemiological studies are quite small.

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REDIRECTION OF HEALTH RESEARCH PROGRAMS

The point of mentioning all this—and I have only touched on a few problems—is that it has taken a lot of effort and time to redirect extensive health research programs in order to respond to a complex major national issue; and to bring these programs to a point where substantial results are starting to come in. Most projects are only on the threshold of producing extensive tangible, i.e., publishable, results. By this time next year, a considerable body of new knowledge will have been reported. Though publishable results are sparse at this time, concrete achievements have been made as a result of the Interagency Energy/Environment R&D Program.

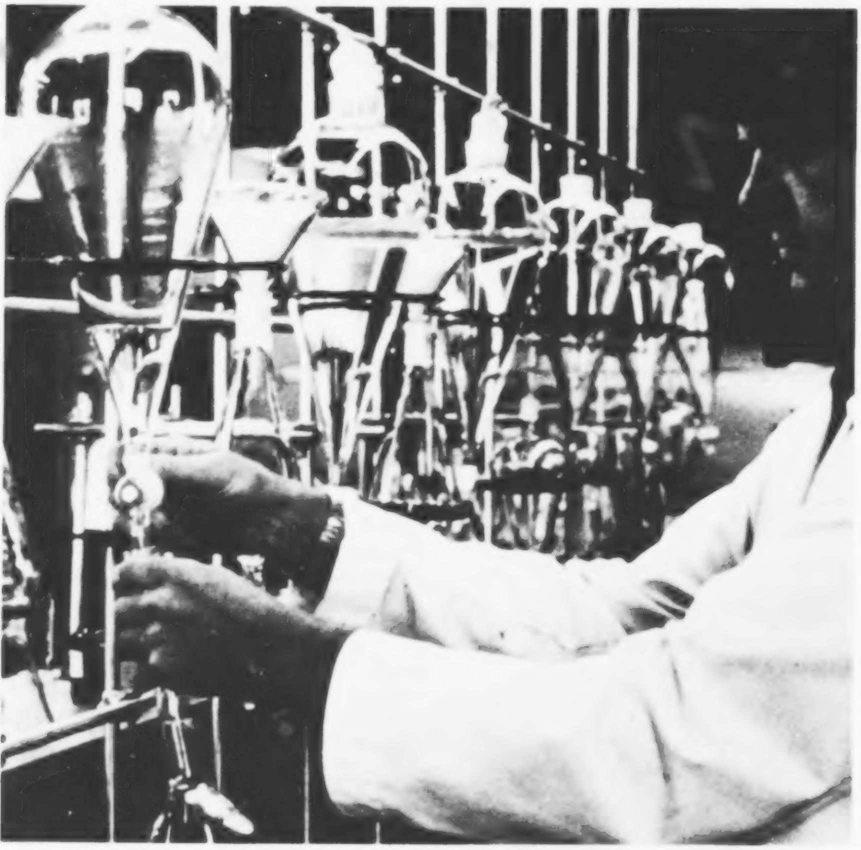
In the detection and evaluation of potential health effects, important accomplishments have included the establishment of information systems and a repository for chemical substances at the Oak Ridge National Laboratory. A data information and retrieval service has been established to compile past and present literature on the mutagenic potential of environmental agents. The Environmental Mutagen Information Center has recently compiled information based on the potential mutagenic activity of petroleum refinery stream effluents and on the toxicity of coal liquefaction products.

A computerized information system for teratology, the Environmental Teratology Information Center, has also been established at Oak Ridge. This system will meet the needs of governmental agencies and scientists for knowledge of the teratogenic potential of environmental pollutants. During the past year, over 7,500 references have been introduced into this system.

Another important research support facility is the chemical repository for energy-related materials at Oak Ridge. This repository was created to receive, store, and disseminate specimens of substances derived from coal gasification and liquefaction, shale-oil production, and effluents from a number of other energy processes.

IN VITRO AND IN VIVO TEST SYSTEMS

Drs. Nesnow, Waters, and Malling of EPA and NIEHS have reported on the use of *in vitro* and *in vivo* test systems to detect and evaluate potential health effects associated with hazardous agents from alternate sources of energy. *In vitro* or nonwhole animal tests are invaluable as prescreens for identifying potential mutagens, cytotoxic agents, and carcinogens.



The Salmonella typhimurium histidine reversion assay of Ames is currently being used as a screen for the identification of hazardous agents from both alternate energy sources and the urine of rats treated with carcinogens. A number of investigators are using the system to evaluate both ambient air pollutants and coal and oil-shale conversion products. Preliminary evidence suggests that the most active components appear to be neutral and basic compounds. Mammalian cells in culture are being used in addition to the microbial system for detecting gene mutations. The metabolites identified as being highly mutagenic are 7,8-dihydro-7,8 dihydroxybenzo(a)pyrene and benzo(a)pyrene-4,5-oxide.

Effects of various energy-related compounds on DNA binding, damage, and repair systems are also being evaluated. 7,12-dimethylbenz(a)anthracene inhibited 50 percent of the thymidine incorporation into DNA after 24 hours' incubation. Inhibition of phage replication was used as an indicator of carcinogenic activity of 12 polycylic aromatic hydrocarbons. The results suggest that some hydrocarbons may directly inhibit phage replication, whereas others may be converted to some other form, presumably within the cell, before demonstrating an inhibitory effect.

IN VIVO SCREENING SYSTEMS

In vivo screening systems are also being used to assess mutagenic activity. Sulfur dioxide, benzo(a)pyrene and 7,12-dimethylbenz(a)anthracene are currently under evaluation as mutagens using the specific locus method in mice. A dominant-lethal study in male mice using benzo(a)pyrene at the maximum tolerated dose has been completed. There is an indication that this carcinogen induces dominant-lethal mutations in spermatozoa. Female mice treated with benzo(a)pyrene or 7,12-dimethylbenz(a)anthracene have shown reduced productivity capacity.

A number of agents are currently under evaluation as teratogens in a variety of test systems. Mice are being treated with X-rays, sulfur dioxide, sulfuric acid, and benzo(a)pyrene; rats are being treated with heavy metals such as lead, and the offspring are being examined for teratogenic effects. A novel approach involves the treatment of mouse and rabbit embryos with SO_x and NO_x in culture, followed by implantation of the cultured embryos *in utero*. Subsequent effects on the developmental process will be noted and compared to animals exposed by inhalation.

COLLECTIVE EFFORTS

As evidenced by the foregoing discussion, significant progress has been made in our collective efforts to detect and evaluate potential health effects associated with hazardous agents from alternate sources of energy. In the future it will be essential to achieve an effective integration of the various bioanalytical methods that have been developed. Increased emphasis on the following areas is needed.

1. Computer-assisted identification (based on known physiochemical, biochemical, and biological structure-activity relationships) of potential genetoxic agents or potentially genotoxic metabolites of the agents in question would be a worthwhile addition to the arsenal of prescreens.

2. A number of the new systems previously described need to be carefully validated with known standards, and quantitative relationships should be established. Methods must be developed to permit existing bioassays to accept crude mixtures and effluents without prior purification. Systems must be designed and implemented that are genetically and metabolically similar to man. *In vivo* test systems, in which a number of parameters such as cytotoxicity, DNA damage and repair, metabolism, mutagenesis, and neoplastic transformation could be measured concurrently, would be a valuable addition to the screening systems available. More emphasis in the area of monitoring the human population for increases in mutations, cancers, and terata is desirable. Further investigation of multiple-agent effects on toxicity, mutagenesis, teratogenesis, and carcinogenesis is essential.

3. The interagency program for *in vivo* animal toxicology was established to evaluate the toxicological hazards of effluents, waste streams, and products of extraction, conversion, and utilization from the various energy technologies by acute and chronic exposure of whole-animal models, using appropriate exposure regimens.

Drs. Coffin and Dixon point out that the program involves not only the actual testing of hazardous materials to establish dose-response relationships under a variety of exposure conditions, but also to identify particular animal strains which, based on their sensitivity to selected pollutants, can be used to model those human organs, systems, or individuals which are most susceptible to that particular stress.

PROGRAM'S PRIME FOCUS

The program focuses primarily on pollutants released during the coal fuel cycle, especially during combustion and/or conversion, and to a lesser extent on pollutants resulting from other synthetic fuels and energy-conservation activities. The program is oriented toward defining dose-response resulting from inhalation exposures, which represent the primary route of exposure to environmental pollutants for a majority of the population. However, the program is placing increasing emphasis on other routes of exposure—e.g., ingestion and dermal absorption, and particularly multiple exposure routes, such as inhalation/ingestion—and their relative contributions to an individual's total body burden, and through interaction study concerning toxicants from other sources, biological interaction with infectious agents, etc.

EPA, ERDA, and NIEHS carry out more than 70 separate research projects in the *in vivo* aspects of toxicology in the Interagency Program. In addition, many similar experiments pertaining to energy are being performed in the base programs of the respective agencies. Many of the projects in these programs are closely interlinked so that much more work in this field is progressing than testing under the Interagency Program indicates.

GENERAL PROGRESS OF PROGRAMS

It is patently impossible in this review to discuss the programs beyond citing some general progress. According to Drs. Coffin and Dixon, progress during the past year has been accomplished on three fronts. First, a normal development of projects with time and an increase of data collection as they get underway can be expected. Second, increased information sharing between the various investigators through conferences and inter-scientific communication has occurred. And third, collection and dissemination, across agency lines, of information relative to developing process availability of specimens for biological testing, which have relevance to the technologies involved, has been accomplished.

The major objectives of the research in metabolism and mechanisms in biological systems are threefold: (1) to improve the capabilities of extrapolated dose-effect, experimentally derived, information to predict critical results of health in man; (2) to provide mechanically, data that can transcend species variation by establishment of generalized mechanisms of damage and repair at the cellular and molecular level; (3) to develop the biological and biochemical methods and systems needed to accomplish these objectives. Underlying these objectives is the need to define the patterns of deposition, distribution, and metabolism which determine chemical dose at the cellular level of critical organic, biological, and physical factors influencing toxicity.

Effects involve all of the major classes of fossil energy-related pollutants (polycyclic aromatic hydrocarbons, aliphatics, and alicyclics), gases, particulates, and trace metals.

Since the thrust of this portion of the program is developmental in nature and highly diversified in terms of methodology, it is at present difficult to summarize in terms of the ultimate objective, namely, improvement of capability to predict health risk to man.

Nevertheless, Drs. Schulman and Stapleton report some highlights: (1) It is clear that carcinogenic hydrocarbons (polynuclear aromatics) bind to DNA, and cells that have produced repair enzymes can partially counteract the damage. (2) It is possible to evaluate repair *in vivo* in critical organs as well as *in vitro* cell cultures. And (3) Data are becoming available that suggest similar types of molecular damage and repair are involved, leading to mutagenesis and carcinogenesis.

Human health research is largely confined to clinical studies conducted by EPA and occupational safety and health studies conducted by NIOSH.

EPA CLINICAL STUDIES— PHASES I AND II

Dr. Knelson reports in his paper that the clinical studies in EPA have evolved in two parallel phases. Phase I is the establishment and maintenance of a clinical studies research facility and the development of new techniques with which environmental conditions can be simulated and their effects assessed. This developmental activity is necessary because of the paucity of prior work in clinical environmental research. EPA has assumed a leading role in this investigation. Phase II is the actual use of those resources in conducting studies. The energy R&D effort figures in both phases of the EMA's clinical studies program. In Phase I the energy program provides the data quality assurance for components of the research system. Phase II consists of the actual use of the resources developed in Phase I for conducting the clinical studies. EPA also supports outside, independent studies similar to those being conducted in-house.

The environmental clinical studies within EPA center on the Clinical Laboratory Evaluation and Assessment of Noxious Substance (CLEANS) facility at the University of North Carolina, Chapel Hill. A product of several years of design and development, this facility is now completed and will shortly begin to test energy-related pollutants.

SULFATE RESEARCH

Studies are in progress to determine the effects of sulfuric acid aerosol on healthy subjects. Depending on the results of this research, other studies will be designed to assess the effects of ammonium bisulfate and ammonium sulfate. The sulfate research, just beginning, is especially important and timely. Many forms of sulfates result either directly or indirectly from all fossil fuel-fired combustion sources. Research is in progress to evaluate effects of carbon monoxide, oxidants, and sulfates. New studies will address nitrogen oxides and other aerosols, such as nitrates. These studies will be an important feature of the Nation's energy program.

Despite the high level of effort associated with CLEANS, it is absolutely necessary that independent studies also be conducted outside of EPA. Such supplemental studies help verify the results of CLEANS and add to a data base broad enough to assess for regulatory purposes the effect of sulfate aerosols on human health. EPA is funding two independent studies of the effects of sulfuric acid exposure, one by the University of Maryland School of Medicine, the other by the University of California.

The EPA Health Effects Research Program will continue to pursue a broad-based, multidisciplinary research program, a large part of which will identify and quantify health consequences of changing energy-production technology. It is clear that tighter homes and a shift to more coal combustion are occurring in this country. Therefore, a larger clinical studies program addressing sulfur oxides, heavy metals, organics, and indoor pollution is indispensable.

The National Institute for Occupational Safety and Health is pursuing a broad program of industrial hygiene and epidemiological investigations which includes the development of improved environmental sampling and analytical chemistry techniques. We will not discuss the analytical chemistry and instrumentation development projects, even though exciting progress has been made in this area. The projects will be presented in detail later today.

HIGHLIGHTS OF NIOSH ENERGY RELATED PROGRAM

The industrial hygiene and epidemiology studies are directed at a number of energy processes. NIOSH and TVA have completed a joint preliminary feasibility study and are initiating, through interagency agreement, a study of worker exposure at coal-fired steam electric generating plants utilizing negative and positive draft boilers, and a retrospective mortality study of about 6,000 employees who worked in coal-fired plants between 1955 and 1972.

Because of the concern for human exposure to asbestos and other fibrous materials, and in anticipation of an accelerated national effort to conserve energy through increased use of insulation, NIOSH has been studying workers exposed to mineral wool fibers. A report on a retrospective mortality study and associated industrial hygiene surveys is expected to be completed later this year.

Research has also been expanded on the effects of the recirculation of indoor air. A seminar is tentatively scheduled for this September to discuss the results of the present contract.

Industrial hygiene investigations of high Btu gasification pilot plants have been performed under contract and were well underway earlier this year. The contract is being expanded to include both low and high Btu gasification processes.

A contract for the study of coal liquefaction processes will be awarded within a few months.

NIOSH is also developing occupational safety and health guideline documents for coal conversion plants. A document on coal gasification pilot plants, now being reviewed by several Federal agencies, will be finalized and transmitted to OSHA and ERDA later this year. Work has begun on a second document to develop safety and health criteria for coal gasification scale-up facilities. Later this fiscal year, a contract will be awarded for similar documents related to coal liquefaction.

Morbidity and mortality studies of former oil-shale workers are ongoing. Most of the cohort members have now been located and their vital status determined. The cohort is quite small, however (600 persons), and the industry is not sufficiently developed to provide very meaningful industrial hygiene investigations. NIOSH is,

energy
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therefore, making a preliminary study of the oil-shale industry in the Soviet Union to determine whether the Estonian experience is similar enough to be used as a predictor of potential future problems in the United States.

Although I have not mentioned a number of projects, these are some of the highlights of the NIOSH energy-related program. I expect that a number of significant results, reports, and documents will be forthcoming within this next year.

CURRENT STATUS OF STUDIES IN ANIMALS

Drs. Hogan and Nelson reported on the current status of extrapolating results of studies in animals, often conducted at high dose levels, to the human exposure situation, usually occurring at much lower dose levels. Most of the tested carcinogens appear to behave in a linear dose response fashion at low dose levels, even if they exhibit a nonlinear response in the experimental dose range. Tight confidence limits for the point-estimate of risk at low dose levels can usually be established for compounds that exhibit a strong linear trend in the experimental dose range.

In conclusion, let me say that the interagency R&D health research program in energy shows promise of making a substantive contribution to our Nation's efforts to provide safe and environmentally acceptable energy sources.

WILLIAM L. WAGNER

B.S., Civil Engineering, M.S., Sanitary Engineering, Virginia Polytechnic Institute; M.S., Radiological Hygiene, University of North Carolina. As Coordinator for Energy and Mining Research, NIOSH, directed research in energy technologies and metal and nonmetallic mining. Experience as radiation physicist for Alaska Department of Health and Social Services on control of ionizing and nonionizing radiation. Extensive involvement in protective plans for radiation related emergencies; developed characterization techniques for radioactive particles, and monitored environmental radionuclide concentrations from fallout from nuclear testing. Currently, Director for Environmental and Energy Research, NIOSH, Morgantown, WV.

questions & answers

Mr. Kesh S. Murthy
Battelle-Columbus Laboratories

Dr. Herbert Lorber
Los Alamos Scientific Laboratory-ERDA

Dr. Harrison R. Hickey
Tennessee Valley Authority

Mr. Alex Green
University of Florida

Dr. Edward S. Rubin
Carnegie-Mellon University

QUESTION:

Dr. Friberg, could you repeat the name of the journal the risk assessment report will be published in?

RESPONSE: Dr. Lars Friberg (Karolinski Institute)

The Environmental Health Perspectives given out from the National Institute of Environmental Health Sciences.

QUESTION:

With regard to the linear versus nonlinear debate, Dr. Friberg gives the impression that in the absence of firm data the symposium decided to take a prudent, easy, and practical course, assuming a linear behavior with zero threshold. However, I got the impression from the rapporteur's summary that there is perhaps some evidence to support the linear hypothesis. Would someone please elaborate on this?

RESPONSE: Dr. Friberg

There is no doubt that there are data which support such linear hypothesis. However, the conclusion was a more general one, meaning that, as there is evidence for certain chemicals of this linear relationship, it was best to use a linear hypothesis generally if there was no evidence to the contrary. This would be in agreement with what is used in radiation protection.

COMMENT: Dr. George E. Stapleton (ERDA)

Dr. Friberg would probably agree that the best evidence for linearity comes from polynuclear aromatic hydrocarbons that are complete carcinogens. Not all of the known agents are complete carcinogens; that is, they do not serve as an initiator as well as a promoter.

There may be other evidence for what we now classify as incomplete carcinogens where the dose response is not linear. From recent experiments, the initiation process which shows linear kinetics is most interesting, but the requirement in some cases is for a promoting agent.

I would also like to indicate that the regulated compounds are not promoters. It may turn out to be very important in the future that some of the hydrocarbon-type compounds need to be assessed in their role as promoters as well as carcinogens. The possibility is being created by the very programs that were talked about today, to actually develop inexpensive and perhaps rapid screens to indicate what compounds serve as promoters. We know only a few now, but there are many compounds that could be promoters, especially the organic compounds.

COMMENT: Mr. Gerald Rausa (EPA)

I am substituting for Mike Hogan from NIEHS who was to address the question of risk extrapolation. I have recently returned from an NIEHS symposium where Mike Hogan and Dr. David Hull have been doing a lot of modeling. There is some evidence which indicates that it is most appropriate to use the linear, nonthreshold hypothesis for several agents.

Dr. Hull's papers on that subject will be available in the not too distant future. That does not mean that all agents exhibit this relationship, but there is indeed some evidence that, as Dr. Stapleton indicated, some agents do.

COMMENT: Dr. Friberg

I think it is important to realize that for several of these compounds for example, benzo-A-pyrene, if there is not an addition, let us say from a power plant, we always have a fairly high background level; so we are basically not down at the very zero dose.

QUESTION:

I wondered what the implications are to the selection of alternative systems in control technology of this linear hypothesis, as opposed to having a threshold below which presumably we can enjoy a healthy environment. Does this mean that we will be driven by that hypothesis in the direction of the as low-as-practicable-approach that has been used for the nuclear industry?

RESPONSE: Mr. William Wagner (NIOSH)

The Occupational Safety and Health Act was meant to be a technology-forcing act. As carcinogens and hazards are identified, the controls in the plants will have to be designed to bring these exposures to a minimum. Would somebody like to comment on the environmental aspects?

RESPONSE: Mr. Rausa

The question really is what is an acceptable risk, and of course, it turns out that what is an acceptable risk to one person may not be an acceptable risk to another. As a consequence, that particular question should be addressed to the decision makers themselves.

Those in the research business are trying to estimate the greatest amount of reliability—what that dose response relationship is and under what circumstances the linear hypothesis is appropriate. The question of acceptability of risk is not necessarily what should be asked of these individuals but rather of the decision makers.

QUESTION:

I was wondering about the significance of the linear hypothesis itself, assuming that you mean linearity all the way back to zero. That says that there is not a threshold, that one molecule is too much. Am I reading that correctly? Is that what the linear hypothesis means?

RESPONSE: Mr. Rausa

There are two types of linear hypotheses. One is linear nonthreshold and the other is linear with threshold. As a matter of fact, there are a number of different kinds of models. Linear nonthreshold essentially means a one hit situation without taking into account the possibility for reparative processes. But on the basis of the data that exist at the present time, there is no doubt that under some circumstances linear nonthreshold is an appropriate approach to use. EPA's cancer assessment group is headed by Dr. Roy Albert, who just recently said that, as far as he is concerned, this is the particular approach that will be used for making recommendations for a number of agents.

QUESTION:

There are several papers published that question the general applicability of a linear hypothesis. A number of years ago a paper introduced a concept of drug potency where things went as D^n times the mean age to 50 percent incidence.

I have done work in the ultraviolet radiation skin cancer, nonmelanoma skin cancer, which suggests age-adjusted rates go as exponentially with dose or approximately as D^2 or D^3, in that neighborhood. The National Cancer Institute gets the same type of result.

I have recently heard that a specialized conference on ionizing radiation dose response curves began to question some of what are regarded as the standard tenets of ionizing radiation dose response work. In particular, the impact of repair mechanisms seems to throw some of these tenets into question.

Perhaps a better model than ionizing radiation would be nonionizing radiation such as ultraviolet, where damage is less violent than in ionizing radiation. I would like your comments on that.

RESPONSE: Dr. Friberg

This was discussed in much detail. For example, we say it has become more likely on micro-dosimetric and theoretical grounds than in the mathematical formulation of the dose response relationship. The frequency of many harmful effects is likely to be represented up to rather high doses by the sum of three terms—one being the background frequency, the second varying with the dose, and the third varying with the square of the dose.

QUESTION:

Dr. Wagner, you started off your talk pointing out that one of the benefits of the interagency program has been to get health scientists and technologists talking to one another; yet, health scientists on this panel, the ones I hear, talk most frequently about carcinogens, mutagens, and things that are generally not regulated in terms of the day-to-day business of the EPA. Today we hear about carcinogens and mutagens. Yesterday we heard about sulfur dioxide, particulate matter, NO_x the same old stuff.

Are the health scientists getting the point across to those who are developing control technology that in addition to characterizing effluents from processes, as they may exist in a crude or raw state, we ought to be trying to characterize the effect of different control technologies on these somewhat esoteric sorts of compounds and species?

RESPONSE: Mr. Wagner

I think that we all recognize the ultimate goal of our research is to develop the control technology that will allow us to use some of the energy sources and conversion processes that are being developed; in other words, this is the bottom line of the interagency energy R&D program.

In NIOSH we have a control technology group who, under the auspices of this funding, will be pursuing a number of different research projects and who will be working with our epidemiologists and industrial hygienists. We are also talking to the technologists, for instance, in the fossil energy group in ERDA, and to those who are actually developing the technologies. In other words, we are trying to identify the raw substances, the by-products, the end products, the waste materials, and the fugutive emissions to determine their human risk, and to identify the points of human contact and then find the controls necessary to minimize or eliminate this contact.

QUESTION:

How is it arrived at that carcinogenesis and mutagenesis were the main threats of fossil fuel combustion? Yesterday, we heard that control technology stresses minimizing sulfur dioxide, oxides of nitrogen, and particles. Among the existing control technologies, do any of them lower the carcinogenic, mutagenic hydrocarbons in the air?

RESPONSE: Mr. Wagner

It is not my opinion that the general thrust of the interagency health effects research program is in carcinogenesis and mutagenesis. This is just one aspect of human health effects.

I briefly alluded to a problem in my overview speech about exposure to mixtures of materials. I do not know and would not want to get into a discussion of what materials are promoters or co-carcinogens; it is a very knotty problem.

I think it is important to realize that, when we get into mixtures, we have a number of insults on the human body, and the effects are possibly going to be quite different, perhaps more severe than when we test systems to the pure substances. There is a great deal of work that needs to be done in this area, particularly in just trying to design the test systems. For instance, how does one collect a fugitive emission and keep it intact in terms of its relative proportions of materials and then expose a bacteria or some cell tissue or cell culture test system to this material. There is a lot of work that needs to be done here, and I think in this area we need to do more work and look at the exposure to mixtures as opposed to pure substances.

RESPONSE: Mr. Rausa

It is inappropriate to conclude that one only keys on carcinogenesis or mutagenesis as the end points. There are other end points of major concern. It just so happens that in the risk extrapolation business, the mathematical analysis that has gone on has addressed that particular question. We do the things we can do, and we can do the arithmetic easier with carcinogenesis and mutagenesis than we can with systems, essentially dysfunctions.

The other techniques that are being used in risk assessment as it pertains to other end points is essentially the gathering together of ad hoc groups to decide the appropriate dose response relationship based on the totality of information which is available, from animal toxicology, epidemiology, and the clinical studies, and how to extrapolate that. You should not go away from here thinking that carcinogenesis and mutagenesis are the only end points of concern.

RESPONSE: Dr. Friberg

I would strongly agree with that. One reason that we have researched this in so much detail in Sweden is that we wanted to have an effect that could be compared with the effects that are thought to be the cause of ionizing radiation. For example, we took the concentrations of benzo-A-pyrene and made some calculations using a linear dose response relationship. The number of cancers to be expected, even with such a conservative approach, from one single coal power plant is very trivial. At the same time, if we take another carcinogenic substance that is emitted in the stack gases such as arsenic, we also end up with a trivial number of cancers. The main problem arises in connection with the emission of coal or stack gases from power plants. We have no idea whatsoever what the carcinogenic potential of the total emission is.

RESPONSE: Dr. Stapleton

In the ERDA program there is almost a complete balance, say, between studies that have to do with mutagenesis, carcinogenesis, and what we call systems toxicology. But I must admit that most of the effort in carcinogenesis and mutagenesis is based on the fact that most of the criteria for standards are not based on late effects, and this is one of the large gaps in information for criteria for the future. It is the real gap of information, say, so far as health hazards.

COMMENT: Dr. Stephen J. Gage (EPA)

After the last session was over one of the things that struck me from the discussion is the mix of present and future problems and technologies. I think Dr. Stapleton put it very well by saying that there is a considerable amount of emphasis on carcinogenic and mutagenic research in the health effects area because these are latent problems that have very, very long time constants. If we do have problems—say, cancers caused by the combustion products from coal-fired plants—we ought to know about this as soon as possible.

And probably as important, we should not launch new technologies without taking the greatest precaution in identifying any latent effects that might be associated with those technologies. That is the reason for the combination of studies which are related to the toxic effects, as well as the carcinogenic and mutagenic effects. And that is why we study coal combustion products along with the products and by-products of the advanced processes such as coal liquefaction and coal gasification.

I thought this short word of explanation might help put that previous session in a little better perspective.

technical discussion

DETECTION AND EVALUATION OF POTENTIAL HEALTH EFFECTS ASSOCIATED WITH HAZARDOUS AGENTS FROM ALTERNATE SOURCES OF ENERGY

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INTRODUCTION

An integral part of health effects related research is the development and utilization of methods that facilitate the detection and evaluation of potential health effects associated with hazardous agents from alternate sources of energy. The final Report of the Interagency Working Group on Health and Environmental Effects of Energy Use (King-Muir Report, November 1974) defined five objective areas for study, three of which are: Objective area No 1: To identify hazardous agents associated with energy technologies; Objective area No 2: To develop more rapid and sensitive biological methods to evaluate dose and damage to man, and Objective area No 5: To determine the processes of damage, repair, recovery, protection and amelioration in biological systems exposed to hazardous agents.

These objective areas encompass an overall program of research and development of technologies associated with the identification of hazardous agents from environmental effluents and the determination of their effect on human health. The Interagency Health Effects Related R & D program has provided support for these areas of investigation. This report summarizes the technological advances that have been made.

A distinction can be made within the human population in regard to levels of exposure to effluents from alternate energy sources. Those individuals who reside or work near energy production facilities may be exposed to high concentrations of effluents. Although this subpopulation represents a small fraction of the total population, it would be highly desirable to routinely monitor this subpopulation for increases in possible toxic and genotoxic effects (i.e., those effects that result from damage to DNA). It might also be advantageous to identify high risk individuals within this subpopulation. The remainder of the overall population is exposed to low or background levels of effluents. These individuals are insulted with chronic subtoxic doses of those agents that have diffused from high concentration areas. Constant monitoring of both high concentration and low concentration areas for the appearance of cytotoxic and genotoxic agents and a continuing program of risk assessment is necessary for the protection of the ecosphere. This monitoring can employ rapid, short-term, sensitive tests organized into tiered or hierarchial levels. The incorporation of redundant test systems is desirable to increase the range and sensitivity of the overall test matrix. The problem of false negatives can be overcome by using a battery of tests, while false positives can be further evaluated by higher-order test systems.

In vitro or non-whole animal tests are invaluable as prescreens for identifying potential mutagens, cytotoxic agents and carcinogens in the environment because they are rapid, sensitive, and low in cost.

IN VITRO TEST SYSTEMS

Mutagenesis Systems Utilizing Gene Mutations in Prokaryotic Microorganisms and Somatic Cells in Culture

The *Salmonella typhimurium* histidine reversion assay of Ames is one of the most thoroughly developed systems for detecting mutagens. This system is currently being used as a screen for the identification of hazardous agents from both alternate energy sources and the urine of rats treated with carcinogens. A number of investigators are using the system to direct the fractionation of both ambient air pollutants and coal and oil shale conversion products. The goal of these investigations is to isolate, identify and evaluate the mutagenic and potentially carcinogenic effects associated with specific hazardous agents found in complex mixtures. Using liquid extraction procedures, preliminary evidence indicates that the most active components appear to be neutral and basic compounds. Further developmental work with the *Salmonella typhimurium* system is underway using a number of derivatives of fluorene. Structure-activity relationships, dose-response curves, and the binding of these compounds (or their metabolites) to cells or macromolecules is being evaluated.

Mammalian cells in culture are being used, in addition to the microbial system, for detecting gene mutations. Detection of these events in Chinese hamster ovary cells is through the use of multiple drug-resistance markers such as oubain resistance, 8-azaguanine resistance, and 8-azadenine resistance. A similar approach is being used with Syrian hamster embryo cells. Both cell systems are being further developed and validated with standard mutagens and energy-relevant hydrocarbons. Chinese hamster ovary cells are also being evaluated for use in a point mutation assay using 6-thioguanine resistance as the marker and metabolites of benzo(a)pyrene, an environmental carcinogen, as the test agents. To date the metabolites that have been identified as highly mutagenic are: 7,8-dihydro-7,8-dihydroxybenzo(a)pyrene and benzo(a)pyrene-4-5-oxide.

Mammalian lymphoid cell culture systems (both human and murine) are being investigated as indicator lines using point mutations at the hypoxanthine-guanine phosphoribosyl transferase and

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argininosuccinic acid synthetase loci (human) and the induction of altered immunoglobulin (murine). Chromosomal breakage using banding techniques and activity in bacterial test systems are also being studied for correlative activity.

A different approach to detecting mutations is being evaluated using multiple loci screening by electrophoretic methods. In Chinese hamster ovary cells, the products of 51 structural enzyme loci have been electrophoretically characterized and electrophoretic shifts following treatment with mutagens have been recorded. This technique avoids many problems associated with single selective systems using recessive mutations and offers theoretical advantages.

A data information and retrieval service has been established to compile past and present literature on the mutagenesis of environmental agents. The Environmental Mutagen Information Center (EMIC), located at Oak Ridge National Laboratory, has recently compiled information bases on the potential mutagenic activity of petroleum refinery stream effluents and on the toxicity of **coal liquefaction products.**

Screening Systems for Chromosomal Aberrations in Mammalian Cells in Culture

Chromosomal aberrations, chromosomal breaks, and sister chromatid exchange are being used as end points to measure the genotoxic effects of environmental mutagens in cell lines derived from the Chinese hamster, Indian muntjac, and deer mouse. The effects of energy-related agents on karyotypic changes in Chinese hamster cells are being studied. Chromosomal aberrations and mitotic disjunctions are being scored in stained preparations. This assay will be extended to human fibroblasts and lymphocyte cell preparations as a potential screen in primary human material.

A host-mediated assay is being developed with human lymphoid cells as target cells. The induction of chromosome damage will be determined after the cells are inoculated into heterologous hosts and the hosts treated with test agents.

Carcinogenesis and Co-Carcinogenesis Malignant Transformation Systems

The carcinogenic activity of selected air pollutants is being evaluated using the C3H10T½ and BALB/3T3 neoplastic transformation bioassays. Metabolic activation systems are presently being coupled to these cell systems to enhance their sensitivity. The C3H10T½ mouse embryo fibroblastic cell line is being further developed by attempting to incorporate biochemical and biological end points for carcinogenesis in addition to morphological transformation; these modifications will help to shorten the assay times. Permanent cell lines of epithelial origin (including human) are currently being established that will be transformable by chemical carcinogens. Since most human tumors are derived from epithelial tissues, these cell lines will be highly relevant as screens for these agents. Syrian hamster embryo cells are being used as a test system for the identification of chemical carcinogens. These cells, unlike the BALB/3T3 or C3H10T½, are diploid and have high levels of metabolic enzymes necessary for converting procarcinogens into their active forms.

The activity of agents, obtained from coal and oil shale processes, that enhance carcinogensis (co-carcinogens) is being investigated using x-rays as the primary insult. Initially, rodent lines were utilized until it was observed that these lines processed DNA lesions induced by alkylating agents in a different manner and to a different extent than did human cells. Caution must be exercised in transposing DNA repair data derived from rodent cell tissue culture to the possible effects of the test agents on human cells.

DNA Binding, Damage and Repair Systems

An investigation will be underway to compare the qualitative and quantitative aspects of a variety of systems to convert benzo(a)pyrene to DNA-bound benzo(a)pyrene covalent adducts. This comparative study will examine differences between cell lines derived from different tissues (including those of human origin) as well as compare *in vitro* systems with *in vivo* ones.

DNA repair processes using unscheduled DNA synthesis are being implemented as a screen using primary rat hepatocytes. A number of standard carcinogens have been screened for their effect on DNA repair activity. In permanent hepatocellular lines, these same agents will be screened for their ability to induce point mutations.

DNA damage in Chinese hamster ovary cells is being studied using alkaline sucrose gradients. A number of methods are being employed for the detection of the DNA in the gradient: use of ethidium bromide and fluorometric detection; post-labelling the DNA with ^{125}I; and use of a high-speed flow system using propidium iodide staining.

The combined properties of ultraviolet light or near ultraviolet light (simulating sunlight) and carcinogens on DNA damage, mutations, and transformation is currently being studied. These two types of radiation differ qualitatively with respect to cell killing in V-79, HeLa, and C3H10T½ cells; and with respect to DNA damage and repair in V-79 and HeLa cells. Consequently, projections made from UV effects to effects expected from sunlight cannot be made with complete confidence.

The effects of metals found in coal fly ash on enzymatic DNA replication using DNA polymerase I (from *M. luteus*) are being studied. Divalent cations inhibit DNA synthesis (as measured by changes in T_m value) and induce error-prone DNA synthesis in the system.

The inhibitory effect of 7,12-dimethylbenz(a)anthracene on DNA synthesis and its possible modification by the hormones diethylstilbestrol and progesterone has been studied using primary cells derived from the uteri of young rabbits and cultured in the presence of radioactive thymidine.

7,12-Dimethylbenz(a)anthracene inhibited 50% of the thymidine incorporation after 24 hours incubation. Progesterone showed a protective effect (about 30%); diethylstilbestrol did not reverse the inhibitory effect of dimethylbenz(a)anthracene.

Correlative Tests for Genotoxic Activity

Inhibition of phage replication was used as an indicator of the carcinogenic activity of 12 polycyclic aromatic hydrocarbons. QB RNA and ØX174 DNA, isolated from the respective phages, were used as infective nucleic acids. When mixed with *E. coli* spheroplasts, the infectious nucleic acids were absorbed by the spheroplast and initiated production of new phage particles. The results suggest that some hydrocarbons may directly inhibit phage replication, whereas others must be converted to some other form, presumably within the cell, before demonstrating an inhibitory effect.

Cytochemical markers for cell transformation and carcinogenesis are being examined using microfluorometry and flow system analysis and sorting. Cellular proteases and esterases are being measured in Chinese hamster ovary, Syrian hamster embryo, and human lung fibroblast cells. Significant differences have been observed between cell types. In WI-38 cells (normal vs viral-transformed), differences in levels of cathepsin B1 and alkaline phosphatase can be used to distinguish the two cell states.

The alteration in cell cycle kinetics and chromatin structure, upon treatment of cells with hazardous agents, is being examined by use of autoradiography and flow microfluorometry. Alterations of certain regulatory processes in cells in culture are being investigated as an indicator of cell damage. The test system used is the inducible tyrosine aminotransferase enzyme in cultured rat hepatoma cells. Regulation of transcription by glucocorticoids and of translation by insulin and cyclic nucleotides, as well as the metabolic turnover of tyrosine aminotransferase and its mRNA can be readily analyzed. The hydrocarbons (benzo(a)pyrene and 7,12-dimethylbenz(a)anthracene) and with Al^{+3} have shown little effect on the regulation of the enzymes under study.

Cellular Toxicity Assay Systems and Organ Culture Toxicity Test Systems

Studies of cellular toxicity using the alveolar macrophage are of interest because the macrophage is one of the first cells to interact with inhaled pollutants. Crude ambient air samples, samples derived from alternate energy sources and metallic ions are being tested using rabbit alveolar macrophages in culture. Cell viability, cell number, ATP content, phagocytic activity, and enzymatic parameters are being used as measures of cytotoxicity. The effect of metallic oxide coated and uncoated fly ash on rabbit alveolar macrophage viability and function is currently being determined. Scanning electron microscopic examination is being conducted to map the elemental distribution within the cells.

Heavy metals such as lead and cadmium have been applied to cell cultures derived from nervous tissue, liver, and muscle. The effects of these metals on general growth parameters, on the induction of binding proteins, and on the developmental expression of differentiated functions are being studied. Lead has been found to concomitantly modulate the levels of Δ-aminolevulinate synthetase and Δ-aminolevulinate dehydratase (enzymes involved in the heme pathway), and induce mitochondrial damage in cultured liver cells.

The effects of cadmium as a pulmonary toxicant are being studied using the guinea pig alveolar macrophage. Cadmium transport, its intracellular distribution and accumulation, its effect on the release of lysosomal enzymes, on phagocytic activity and endogenous respiration are being measured.

Tracheal rings from hamsters have been exposed to oxides of manganese. The effects of these metallic oxides on mucociliary beating frequency, tracheal morphology, and ATP content after exposure have been determined.

In Vitro Metabolism, Metabolic Activation, and Detoxification Systems

Using highly sophisticated analytical techniques, the metabolism of a number of hydrocarbons (including benzo(a)pyrene) is being studied in a number of cell lines derived from fetal epithelial (intestinal, foreskin) tissues. Particular emphasis is being placed on establishing the existence of the ultimate carcinogenic metabolites of these hydrocarbons. Enzymatic kinetics and qualitative variations in carcinogen metabolism between these embryonic cells and rodent cell lines are being compared.

IN VIVO SCREENING SYSTEMS

Mutagenesis Systems Utilizing Gene Mutations in Mammals

Sulfur dioxide, benzo(a)pyrene and 7,12-dimethylbenz(a)anthracene are currently under evaluation as mutagens using the specific locus method in mice. This test system evaluates transmitted gene mutations in mammals.

A new mouse strain is being developed to maximize the sensitivity of a point mutation assay. Inbread strains of mice containing specific variants are being backcrossed to the C57B/6J mouse. Starch gel electrophoresis is used to identify up to nine loci and to follow them throughout the course of the genetic experiments. A polygenic assay for induced point mutations in mice is being developed. DBA/2J mice will be treated with triethylenemelamine, and eight phenotypic traits will be measured.

Electrophoretic methodologies for detecting a variety of point mutations are currently being employed by a number of investigators. Characterization of esterases from plasma, red blood cells, and kidneys of C57B/6J and DBA/2J mice and their F$_1$

offspring, using two dimensional analysis, is currently underway. The isoelectric point of each esterase band will be determined. Another approach is to develop a simple mammalian test system where differences in electrophoretic mobility and inactive enzyme changes will be detected at the same loci. Using two inbred mouse strains, which differ with respect to nine enzyme loci, tissue samples of F_3 offspring will be analyzed.

Histochemical methods are being developed to detect point mutations in mouse sperm for the following enzymes: α-glycerophosphate dehydrogenase, lactate dehydrogenase, and succinate dehydrogenase. Using standard staining procedures and specific enzyme inhibitors, it should be possible to detect active site mutations in these spermatozoal enzymes. These mutations will be established by counting stained and unstained cells using computer-assisted microscopy.

Genetic Analysis of Chromosomal Damage in Mammals and Plants

The induction of chromosomal aberrations in mouse germ cells is being studied with two carcinogens. A dominant-lethal study in male mice using benzo(a)pyrene at the maximum tolerated dose has been completed. There is an indication that this carcinogen induces dominant-lethal mutations in spermatozoa. The association between dominant-lethal and heritable translocations is being investigated. Female mice treated with benzo(a)pyrene or 7,12-dimethylbenz(a)anthracene have shown reduced reproductive capacity.

An applicable system for *in situ* screening of the ambient environment is the *Tradescantia* assay. This plant mutation system is quite sensitive to airborne mutagens and ionizing radiation. The further development of this assay towards increased sensitivity and lower background through crossing and selection is underway. A vehicle for environmental screening equipped with *Tradescantia* growth chambers and auxillary air monitoring equipment has been constructed and is presently undergoing field trials.

Carcinogenesis and Co-Carcinogenesis Systems

Pulmonary carcinogenesis studies using BALB/c and C57B/6J mice, strains having different incidences of spontaneous tumor formation, are in progress. The objectives are to obtain information on the mechanisms of spontaneous tumor formation and to determine whether pulmonary carcinogens act additively or synergistically.

In a liver tumor system, the effects of dietary benz(a)anthracene on rats previously treated with 2-acetylaminofluorene is being evaluated. Previous studies have shown that phenobarbital, DDT, and butylated hydroxytoluene have enhanced hepatocellular tumor formation induced by 2-acetylaminofluorene. Preliminary data reveals that 0.025% dietary benz(a)anthracene exhibits little or no tumor enhancing activity.

A unique approach to carcinogenesis bioassay involves the use of the fish, *P. formosa*. In a host-mediated approach, cells from these fish are treated with an agent, injected into recipient fish, and tumors scored one to two years later. Alternatively, the fish are exposed directly with the agent. The carcinogens 7,12-dimethylbenz(a)anthracene and 7,12-dimethylbenz(a)anthracene-5,6-oxide are being tested in this system.

DNA Binding, Damage, and Repair

In vivo DNA repair tests are being developed to measure the effect of the exposure of hazardous agents on the repair of DNA damage in various organs and tissues. These results are being correlated with measurements of cytogenetic aberrations.

Benzo(a)pyrene and 7,12-dimethylbenz(a)anthracene are being studied for their ability to induce unscheduled DNA synthesis in sperm of C3H mice. An increase in unscheduled DNA synthesis was detected in sperm of males treated with 7,12-dimethylbenz(a)anthracene. A slight, though not statistically significant, increase in incorporation of radioactive-thymidine into the germ cells of benzo(a)pyrene-treated mice was noted.

Teratogenesis Bioassay Systems

A number of agents are currently under evaluation as teratogens in a variety of test systems. Mice are being treated with x-rays, asbestos, sulfur dioxide, sulfuric acid, and benzo(a)pyrene; rats are being treated with heavy metals such as lead, and the off-spring are being examined for teratogenic effects. A novel approach involves the treatment of mouse and rabbit embryos with SO_x and NO_x in culture followed by implantation of the cultured embryos *in utero*. Subsequent effects on the developmental process will be noted and compared to animals exposed by inhalation.

A computerized information system for teratology, the Environmental Teratology Information Center (ETIC), is being established at the Oak Ridge National Laboratory. This system will meet the needs of governmental agencies and scientists for knowledge of the teratogenic potential of environmental pollutants.

Toxicology Systems

An inhalation study is directed towards determining the qualitative and quantitative biochemical changes in lungs of animals exposed to pollutants derived from energy sources. It has been observed that oxidant pollutants including ozone, nitrogen oxides, sulfur oxides, sulfates, and sulfuric acid generally depress lung enzymatic activities at acute exposures. At less toxic concentrations, an elevation occurs after an initial depression. Reversion to control levels appears within 20 days of exposure.

In another investigation, specific bioindicators of exposure to nitrogen dioxide and sulfur dioxide are being sought from rats after inhalation. Changes in circulating plasma neutral lipid, alterations in the immunoglobulin fraction of serum proteins, and hormonal-induced changes in biogenic amine levels in both brain and plasma have been observed in rats treated with sulfur dioxide.

Studying early changes in lung cell cytology by flow system analysis techniques offers a rapid and wide-ranging method for determining cytotoxicological effects. Lung cells from controls and Syrian hamsters exposed to physical and chemical agents associated with energy technologies are being processed with a multiparameter cell separator and multiangle light scatter system. Using this method and staining techniques, the following parameters have been measured: DNA content, total protein, esterase activity, cell size, and nuclear and cytoplasmic diameters. Differences in these parameters are being correlated with the exposure to toxic agents.

Pulmonary alveolar macrophages exposed to sulfur dioxide *in vivo* are being studied for membrane lesions using spin label techniques. This investigation has been designed to correlate the formation of membrane lesions with lysosomal activity, cAMP, DNA/RNA synthesis, respiratory capacity, and membrane-bound enzyme activity.

A mouse oocyte system is being developed as a measure of chemical toxicity of teratogens, cytotoxic heavy metals and hydrocarbon pollutants, which are administered to the pregnant mother during gestation and to offspring postnatally. Quantitative dosimetry is provided by biochemical and chemical assays. Surviving oocytes are enumerated in ovaries after exposure and compared to unexposed controls.

In Vivo Metabolism, Metabolic Activation, and Detoxification Systems

The lungs of rabbits exposed to acid mists and particulates are being used in an isolated perfusion model to measure the metabolism of benzo(a)pyrene. Individual benzo(a)pyrene metabolites are being separated and quantitated by chromatographic techniques. The effects of inducers of microsomal enzyme activity administered to the whole animal, as well as the effects of benzo(a)pyrene adsorbed on particulates, are being examined.

Tests Involving the Immune Surveillance Systems

The influence of effluents from alternate energy sources on alterations in the mouse immune system, particularly the respiratory immune system, is being evaluated. Cell-mediated immunity, the effect on killer cells, and mitogen-induced transformation will be tested using mixed lymphocyte cultured. Humoral immunity will be tested using mitogen-induced transformation, antibody production by lymphocytes, and antibody titers. In another study the effect of environmental agents on the development of the immune response in mice is being examined. Mice are injected with hazardous agents at key stages in their immunological development, and specific humoral and cell-mediated immunologic responses are assayed. Dose-response relationships using standard carcinogens are being established. Large doses of 3-methylcholanthrene affect the production of antibody-forming cells more than the cell-mediated response.

Rabbits will be exposed to effluents from alternate energy sources (coated fly ash, crude effluent particles) by inhalation, and the following parameters assayed: morphology, viability, phagocytosis, respiration, numbers, response to macrophage migration inhibition factor, bacteriocidal activity, lysosomal enzymes, and AHH activity; induction of autoimmunity directed against lung tissue; nucleic acid synthesis in alveolar macrophages; and cAMP levels in pulmonary tissue.

Combined Protocols and Correlative Tests

A combined testing protocol is being developed to carry out the following studies in a single animal test: DNA repair in germinal cells; micronuclei test; metaphase analysis of bone marrow; DNA repair in somatic cells; spermatocyte tests; and analysis for active metabolites in blood and urine. Standard mutagens and environmental agents will be used to validate and calibrate these seven tests.

Sperm morphology, as an indicator of exposure to hazardous agents, is under scrutiny as a viable, rapid, and quantitative test system. The sperm from mice and hamsters receiving subacute or chronic exposures by various application routes of test agents will be examined for abnormal morphology, and these results related to dosage and time after exposure. Preliminary results indicate that both species have similar qualitative responses. The development of automated scoring of these abnormalities by fluorescent dye uptake is progressing.

An extremely important support facility for these and other kinds of research is the establishment of a chemical repository for alternate energy source materials. This repository is located at Oak Ridge National Laboratory and receives, stores, and disseminates specimens of materials derived from coal gasification, shale oil development contractors, and particulate effluents from a number of sources.

Tests to Identify Humans Exposed to Hazardous Agents

Screening of the human population for changes in mutation rates is the goal of the following project. Antibodies to each of two types of fetal hemoglobin are being produced and will be used to search for individual mutant cells within a population of cells. Some monospecific antibodies to variant human hemoglobin have been acquired and purified using affinity chromatography. These antibodies will be used in developing tests for detecting human mutation rates.

The development of tests to screen the human population for exposure to trace and heavy metals is currently underway. The levels of a number of these metals will be analyzed by chemical means from human tooth enamel, and the results subjected to statistical pattern recognition analysis.

Future Emphasis

As evidenced by the foregoing discussion, significant progress has been made in our collective efforts to detect and evaluate potential health effects associated with hazardous agents from ultimate sources of energy. In the future it will be essential to achieve an effective integration of the various bioanalytical methods that have been developed. Increased emphasis on the following areas is needed.

Computer-assisted identification (based on known physiochemical, biochemical, and biological structure-activity relationships) of potential genotoxic agents or potentially genotoxic metabolites of the agents in question would be a worthwhile addition to the arsenal of prescreens.

A number of the new systems previously described need to be carefully validated with known standards, and quantitative relationships should be established. Methods must be developed to permit existing bioassays to accept crude mixtures and effluents without prior purification. Systems must be designed and implemented that are genetically and metabolically similar to man. In vivo test systems, in which a number of parameters such as cytotoxicity, DNA damage and repair, metabolism, mutagenesis, and neoplastic transformation could be measured concurrently, would be a valuable addition to the screening systems available. More emphasis in the area of monitoring the human population for increases in mutations, cancers, and terata is desirable. Further investigation in the area of multiple agent effects on toxicity, mutagenesis, teratogenesis, and carcinogenesis is essential.

INTERAGENCY ENERGY/ENVIRONMENTAL PROGRAMS ON ANIMAL TOXICOLOGY

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The nation faces great changes in sources of energy due to problems associated with petroleum. Future projections call for increased use of coal by direct combustion and the development and application of new or alternate technologies. Health problems associated with increased coal use are those of increased effluents by virtue of the increased total combustion; the balance of studies must be made between total increased combustion and greater use of control devices, the effect of beneficiation processes to remove sulfates, and the development of alternate combustion methods. In addition, it is projected that coal will be utilized to produce the so-called syn fuels by gasification and liquefaction. These processes pose new toxicological problems. Synthetic fuels production from such non-petroleum sources of combustible hydrocarbon as oil shale and tar sands also are under study.

These problems pose a great challenge to toxicologists because it appears possible for the discipline of toxicology to have an input into these technologies by working hand in hand with the process people to develop new, safe, clean technologies for the production of energy.

In order to accomplish these ends, an enormous effort is required that is beyond the accomplishment of any single agency in manpower, facilities, or budget. Furthermore, in order to be successful, a number of variant viewpoints are essential to adequately protect the health of the population while at the same time proceeding with all possible speed to meet this urgent goal. For these reasons an interagency toxicological program of considerable size has been mounted that is designed to cover extraction, modification, conversion, and combustion of coal and its synthetic products and the extraction, refining and combustion of new sources of hydrocarbon fuel. Included in the program also is the study of various mineral fibers that is geared to the expressed needs of the conservation of energy via insulation and the exposure of workers and the population at large to mineral fibers during extraction processes. Health risks are being evaluated from the standpoint of occupational risk to miners and workers in other extraction processes, and during conversion to the finished combustion product. The processes are also being considered from the standpoint of point sources for risk to the general population through escape of airborne or waterborne effluents or wastes, and risk to the population at large through contribution of combustion and conversion effluents to the total ambient mix in air or water.

The animal toxicological program has the following objectives: to provide information on general toxic hazards through acute or chronic exposure by appropriate routes; to determine the effects in interacting systems such as combined pollutants or presence of biological agents such as carcinogens from other sources or infectious diseases; and to validate data from chemical or in vitro biological tests. The Environmental Protection Agency is heavily involved in defining animal dose-response relationships for numerous air pollutants to provide support for their regulatory activities. In cooperation with ERDA, EPA is incorporating in vivo systems to quantify those potential hazards associated with emerging energy technologies such as coal conversion and shale oil development, so that pollution abatement or control activities can be initiated during the development stages of a particular process rather than an expensive retro-fit application. In ERDA's program, in addition to the influence of chemical effluents, the effects of nuclear energy pollutants and non-ionizing radiation on intact organisms are addressed. NIEHS provides basic research work in the areas of target organ toxicity, mutagenesis effects on germinal cell development (oogenesis, spermatogenesis), teratological studies, and inhalation modeling. NIEHS performs studies relevant to the protection of the health of industrial workers.

The whole-animal testing program provides several direct and indirect benefits. By coupling the animal testing program with the bioscreening and cellular toxicologic efforts, a cost-effective, comprehensive basis is developed for predictions of adverse human health impacts from energy related pollutants. As more definitive dose-response relationships are developed, technology development as well as regulatory activities can concentrate their efforts as needed. Documentation addressing pollutant specific, process specific, or biological testing protocols will be developed as appropriate.

In addition to the primary benefits of the program, several secondary benefits arise. The bioassay program provides data to direct any subsequent whole-animal testing, and in return receives information that is used in the validation of the testing protocols. In addition, whole-animal studies provide insight into target organ toxicities for use in the cellular toxicology program and in the clinical and epidemiological programs.

Although there is a noteworthy effort using whole-animal studies (coupled with in vitro programs) to define the hazards associated with pollutant exposures, several areas have been singled out as requiring more emphasis. There is an urgent need to have available more testing methods that reliably indicate subtle organ or system dysfunction prior to the onset of irreversible damage. The effects of energy related pollutants on the reproductive function of populations chronically exposed at low levels must be clearly defined. Current interest focuses on gross indications of reproductive damage (e.g., birth defects), but must also address the more subtle impacts on population fertility and fecundity. In addition, the possible interactive effects from multiple pollutant exposures must be better defined, and should not be restricted to combinations of only energy-related pollutants or sources. Further work to specify toxicologic manifestations of inhalation exposures, especially in stressed or susceptible populations, is needed, as is better definition of multiple exposure pathways in relation to the total body burden concept.

The program involves not only the actual testing of hazardous materials to establish dose-response relationships (under a variety of exposure conditions) but also the identification of particular animal strains which, based on their sensitivity to selected pollutants, can be used to model those human organs, systems, or individuals which are most susceptible to that particular stress. The emphasis of the animal toxicology program is on developing dose-response relationships for adverse pulmonary effects (e.g., dysfunction, carcinogenesis) caused by air pollutants from coal conversion or combustion, shale oil extraction and combustion, and near term energy conservation technologies.

That portion of the interagency health effects-related R&D program involving animal toxicological studies can be described in terms of several parameters, as is evident in Table 1. The program is intended to provide quantitative data describing pollutant effects on whole animal systems (*in vivo*) to complement those areas where *in vitro* bioscreening or cellular toxicology efforts are being applied, since the validity of all these methods is at this time uncertain. *In vivo* studies defining the long-term, low-level pollutant exposure hazards from single as well as multiple exposure pathways (e.g., inhalation/ingestion), and teratogenicity testing on selected materials are progressing. The program also addresses those non-lethal aspects of pollutant exposures that reduce an organism's life-span, or produce decrements of functional activity in a particular system of sufficient magnitude to make the host more susceptible to damage from other stresses.

A large portion of the animal toxicology program is devoted to the elucidation of various pollutants' effects on mammalian pulmonary systems under a variety of exposure conditions. Physiological effect resulting from localized deposition and/or retention of pollutants, a loss of functional integrity in the entire system, a reduction in immune response capacity, and various metabolic and biochemical and pathologic alterations are being considered. To a large extent, the program addresses the impacts on pulmonary effect of criteria pollutants (including their atmospheric progeny), and in particular SO_x, NO_x, and respirable particles. Parametric studies are under way to define the inter-relationships between pollutant combinations that can result in significant interactive effects (e.g., synergism).

TABLE 1. ANIMAL TOXICOLOGY TEST PROGRAM

HEALTH END POINTS

Carcinogenicity

Mutagenicity

Teratogenicity

Toxicity

Physiological damage
(e.g., Deposition/retention, functional capacity, metabolic or biochemical changes)

TARGET ORGANS/SYSTEMS

Pulmonary

Cardiovascular

Reproductive

Central Nervous System

Immune

Various Isolated Organs
(e.g., liver, kidney, etc.)

AGENTS OF CONCERN

Aerosols (including fibrous amphiboles and other mineral fibers, and secondary formation products)

Criteria Pollutants (i.e., SO_x, NO_x, oxidants, suspended particulate matter, hydrocarbons, and carbon monoxide and their atmospheric progeny)

Electromagnetic and Corpuscular Radiation (ionizing and non-ionizing)

Organic Compounds
(esp. polynuclear aromatic hydrocarbons)

Trace Metals
(e.g., Pb, Cd)

Reproductive, CNS, and immune systems response to various pollutant exposures (including electromagnetic and corpuscular radiation) are being described by whole-animal studies. *In vivo* germinal cell studies (mutagenic potential, viability), and teratogeny studies for a number of pollutants including SO_2, selected polynuclear aromatic hydrocarbons, and tritium, are under way, as are studies to define CNS effects from trace metal exposures, organic compounds, and non-ionizing electromagnetic radiation. Immune system response (in particular, pulmonary immune systems) to pollutant stressors are being defined so that indirect effects on whole-animal infectivity resulting from pollutant exposures can be determined.

The animal toxicology program focuses primarily on pollutants released during the coal fuel cycle, especially during combustion and/or conversion, and to a lesser extent on pollutants resulting from other syn fuels and energy conservation activities. The program is oriented toward defining dose-response resulting from inhalation exposures, which represents the primary route of exposure to environmental pollutants for a majority of the population. However, the program is placing increasing emphasis on other routes of exposure (e.g., ingestion, dermal absorption) and particularly multiple exposure routes, such as inhalation/ingestion, and their relative contributions to an individual's total body burden and through interaction study concerning toxicants from other sources and biological interaction with infectious agents, etc.

EPA, ERDA, and NIEHS make major contributions to the animal toxicology program, with each reflecting their legislative mandate. Progress during the past year has been accomplished on three fronts. The first, a normal development of projects with time and increase of data collection as they get under way. The second is increased cross-fertilization between the various investigators and those involved through conferences and interscientific communication along these respective lines of interest. And third, through the collection and dissemination across agency lines of information relative to developing process availability of specimens for biological testing which have relevance to the technologies involved. An interagency program between ERDA and EPA has been undertaken to assure that investigators have available characterized material from the various technologies through the establishment of an energy materials repository.

The bottom line for toxicity testing is its feedback to the technology. The ultimate function of toxicology is to detect potential hazards in a particular technology with the end in view of guidance of the process to eliminate the hazard without obstructing its development. In order to accomplish these ends it is essential that there be close interaction between engineers and other scientists concerned with the technologies involved, and with the biologists and other scientists concerned with animal toxicology. Progress is being made on this front.

PROGRAMMATIC EXAMPLES

More than seventy separate research projects are being carried out in the in vivo aspects of toxicology in the interagency program. In addition, many similar experiments pertaining to energy are being performed in the base programs of the respective agencies. Many of the projects in these programs are closely interlinked so that much more work in their field is progressing than the interagency testing indicates.

It is patently impossible in this review to discuss any details of the programs beyond citing a few examples of work in progress. For instance, in the wide ranging NIEHS program, attention is being given to the influence of heavy metals on the functional integrity of the cardiovascular system in which exposure of rats to cadmium shows a direct relationship between the intake of cadmium chloride and changes in renin, a component of the blood pressure regulating mechanism.

Another interesting component of the NIEHS program relates to the metabolism and disposition of selected radio-labeled hydrocarbons and some of their chemically reactive epoxides in the isolated rabbit lung, and by reconstituted pulmonary biotransformation systems. These (as others of the NIEHS program) are basic studies which may ultimately contribute better ways to study the toxicology of the energy problem.

In the ERDA program, among other things, a great deal of attention is being given to carcinogenesis. One project is testing the carcinogenicity of shale oil, synthetic fuels from coal conversion, and petroleum crude by mouse skin bioassay. In these studies, quantitative comparisons are being made between the polycyclic aromatic hydrocarbon fraction of these fuels in order to determine the role of this fraction in the totality of the carcinogenic potential. Genetic experiments such as specific locus studies and bacterial mutagenesis tests are being applied to these same fuels. Another series of experiments in the ERDA program is concerned with examining the influence of oil shale and spent retort material on the lungs of experimental animals both by intratracheal instillation and inhalation exposures.

The EPA program is aimed at obtaining data that will be useful for the application of control measures and the setting of emission standards for both criteria and non-criteria pollutants. Studies are underway to evaluate the health hazards associated with coal burning in power stations by exposure of animals to reconstituted particulate emissions. Among the parameters studied in these experiments are those concerned with the defense of the lung against exogenous insults such as other chemicals and bacterial infection.

Another project of EPA is to examine the cancer producing potential of nonorganic substances. These experiments are to determine the oncogenesis of mineral fibers released during extraction and beneficiation of minerals directly and with added cofactors. Comparisons are being made to asbestos and other minerals on the basis of the chemical and physical properties of the fibers and their interaction with organic substances.

DISCUSSION

This short review of the animal toxicology connected with the interagency program has dealt with principles and overall objectives rather than a detailed discussion of the individual projects. The thrust of this program is to establish dose-response relationship between energy-related exposures and effects so that an estimate may be made of acute or chronic exposure from which extrapolation to humans may be made. Animal exposure of this kind is capable of producing important information for correlation with observed effects on human beings by community, occupational, or experimental exposure. By such correlation, better information can be developed concerning such factors as mechanism, dose-response, and interaction with other agents.

In those cases in which the potentially hazardous influence is newly introduced into the environment, no observation or spontaneous human exposures will be available. Experimental exposure of human volunteers has limited potential because of obvious restrictions on the application of this method to seriously toxic materials. Therefore, whole-animal toxicology must be relied upon to provide a great deal of the human risk development information for the energy program.

Another important aspect of the animal toxicology program is that of verification of the *in vitro* screening systems. These methods have enormous potential utility in toxicology. However, despite a very large effort, such methods account for too little definite information regarding their potential in accurately predicting toxicological hazard.

In vitro screening and whole-animal toxicology is being carried on in an unprecedented volume in the energy program. This program offers an unique opportunity to match these two methods by performing controlled correlative tests on identical materials and chemicals. Information of this type will be of great benefit not only to the energy toxicological program, but a valuable spin-off for the science of toxicology in general.

METABOLISM, DAMAGE, AND REPAIR OF DAMAGE OF ENERGY-RELATED CHEMICAL AGENTS

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INTRODUCTION

It is two years after the first meeting on the interagency energy-environment research and development program. That meeting which laid the plans for the multiagency-multidisciplinary program was a relatively simplistic coverage of plans, strategies, and the various philosophies and responsibilities of the involved agencies.

Since that time a number of events have happened in the health effects area. In ERDA the energy-related program has grown from the original 2.6 million in pass-through funds to about 17 million in biological studies related to energy technologies other than nuclear energy. Almost all of the research efforts covered in the two segments to be reported were objectives 3 and 5 of the original "King-Muir" plan namely "Metabolism of Hazardous Agents" and "Damage Repair and Recovery Processes" have been transferred to the ERDA program and budget.

In addition, the rather simplistic subdivision of objectives may or may not have anticipated the amount of interaction that would occur among objectives or the amount of support both metabolism and mechanism studies would provide to the other objectives.

PROGRAM ORGANIZATION AND PROGRESS

This segment of the health effects program in ERDA's base program is developmental in nature and at present is categorized as part of the "supporting research" program which includes the following objectives:

- A. To develop useful short-term cellular and molecular screening methods for mutagenesis, carcinogenesis and systems damage.
- B. To develop useful early indicators of damage and methodology for their application for monitoring cytological and biochemical changes in exposed experimental animals and humans.
- C. To improve knowledge of normal organ, tissue and cell structure and function to better recognize damage.
- D. To define the basic mechanisms of pollutant interaction with key subcellular and molecular structures that are common to all species and to define the repair capability for such damage.

A. To Develop Useful Short-Term Screens

A large number of potential screens are under development which require not only cellular and molecular systems but also the necessary methodology and instrumentation to make them useful for their specific application. For example, it would be ideal to use human cells, and human chromatin rather than DNA for this purpose. Moreover it would be most advantageous to use "normal" human cells rather than a number of available established cell lines which are easy to grow perhaps because they are "abnormal" in some respects. Some progress has been made in developing human lymphocyte-lymphoblast and fibroblast cultures for mutagenesis and oncogenic transformation. Some claims are made for success in isolating and culturing mouse alveolar cells and attempts are being made to obtain the human counterpart.

Of equal importance is development of organ, tissue and cell cultures from those experimental animals presently used for dose-effect studies. Two examples are skin tissue cultures and outgrowth cell cultures, and the tracheal explant cultures and outgrowth cells, presently in use in another health effects program reported at this meeting.

There is a need to extend the lifetime of such cultures and to shorten the time between the exposure and observable expression of mutation and malignant transformation. Progress has been made in both areas.

In addition, there is an established need for perfecting the use of fast flow fluorometry for not only handling large numbers of cells, but also sorting of various classes of normal cells and fluorescent indicators of altered damaged cells. Such methods are under development in several NIEHS and ERDA laboratories.

B. To Develop Useful Indicators of Damage

The major efforts in this program relate to organs or tissues at highest risk for exposure, namely the respiratory tract and the skin. Minor efforts involve liver and the gastrointestinal tract. The development work on the lung and skin overlaps all aspects of organ toxicology and carcinogenesis and ranges from whole animal to organ and tissue culture and cell cultures derived from these systems.

Indicators of respiratory tract damage emphasize two primary cell systems, the macrophage because of its involvement in lung clearance and immune response, lung epithelial cells in terms of irritation and resulting enhanced cell turnover and its role as a prime target cell in cancer. Methods are available or under development to sample these cell types for cell turnover and loss or change in function as indicators of early damage and progression to latent diseases including cancer. Efforts in many laboratories are devoted to non-destructive indicators of impaired physiological function in whole animals.

The research with skin and liver is primarily devoted at present to detection of cytological and biochemical changes that correlate in time with promotion and progression of cancer.

The work on the gastrointestinal tract is aimed at detection of changes in absorption and excretion caused by toxic metals. While these studies have as their chief objective measurements of damage, they also involve work on retention and distribution of toxic metals in key organ systems and thereby serve a double function.

C. To Improve Knowledge of Normal Organ, Tissue and Cell Structure and Function

The emphasis in this part of the program is on better understanding of the organ systems established or suspect as critical in terms of (1) route of entry upon exposure or (2) need for rapid cell renewal for integrity. The research this relates to basic biochemical function of lung surface cells, lung surfactants and membranes. The hematopoietic and immune systems are suspect as critical because of the potential sensitivity of the stem cell populations. Principal efforts are devoted to understanding the molecular mechanisms which regulate the differentiation of the various classes of leukocytes and the factors which interfere with the regulation in diseases including leukemias.

In terms of methodology efforts are under way to (1) culture hematopoietic stem cells in semipermeable membrane chambers and (2) to fractionate and sort various types of keukocytes based on size, shape, biochemical and immune function. Reasonable success has been obtained in both types of efforts.

D. To Define the Basic Mechanisms of Pollutant Interaction with Important Subcellular and Macromolecular Structures

A large number of efforts in both the ERDA and NIEHS base and pass-through programs are covered by this objective. The need for such work is at least two-fold (1) to evaluate basic mechanisms of damage at a level that may transcend mammalian species as an aid in extrapolation of information from experimental animals to man and (2) to suggest possible protection or therapy against damage.

The research on molecular repair has a solid foundation based on the detailed information on radiation damage and its repair.

Heaviest emphasis in most projects is on mutagenic and carcinogenic hydrocarbons on DNA and good progress has been made for a few known agents. For example, it is now known that carcinogenic polynuclear hydrocarbons in the activated state bind to DNA and show first order kinetics of binding in terms of exposure level. Similar kinetics have been shown for gene mutation for several hydrocarbons. Likewise, similar kinetics have been shown for the initiation phase of carcinogenesis and progress is being made in these programs and those of the National Cancer Institute in defining the specific binding and damage site(s). Far less is known about the sites of action in cancer promotion as compared to the initiation process.

Although some progress has been made in studies of repair in procaryotic organisms there is a need for much more work in mammalian cells and especially human cells. Such work is just beginning and is hampered by the lack of repair-deficient mutants except for cells derived from humans with xeroderma-pigmentosum. Efforts are underway to select such mutants using novel methods.

By far the most interesting prospects in much of this work is the likelihood of demonstration that gene mutations and initiation of carcinogenesis have the same molecular mechanism. Coupled with this is the interesting hypothesis that "error prone" post-replication repair is involved in the mechanism. The program described as well as that sponsored by other agencies is providing the tools to accelerate the test of these hypotheses.

Work is far less advanced in defining the molecular basis for the promotion and progression stages of carcinogenesis. Several projects are exploring the prospects of simple short-term *in-vivo* and *in-vitro* screens for this process. It is not unlikely that some of the hydrocarbons involved in a number of synthetic fuel processes may be efficient promoters and mixtures contain both types of agents.

Again, as mentioned earlier, new methodologies and instruments are important components in the research described.

SUMMARY

This segment of the interagency energy health effects program is developmental in nature and is not easily adapted to the same type of progress analysis as do the more applied segments. The diversity of efforts, likewise, present difficulties in summarization.

Our view is that this is a development program with systems, methods and instrumentation on its way to application for most of the other segments of the overall program.

Judged in those terms, it appears that reasonable progress is being made.

CLINICAL RESEARCH RELATED TO ENERGY

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INTRODUCTION

The purpose of this paper is to highlight the supplemental support which the Interagency Energy R&D Program is providing to EPA's Clinical Studies. The energy health program began in FY 1974. It has enhanced the Agency's base research effort by focusing more clearly on health effects created by alternate or modified energy sources.

Overall, the energy program has been designed to (1) determine the nature of pollutants emitted from alternate energy technology, (2) develop health intelligence suitable for developing regulatory policy and (3) assist in identifying new energy-producing technology having fewest threats to public health. The classes of pollutants addressed in the energy related research are those which are most frequently emitted from fossil fuel fired sources. The pollutants emphasized are those which can be classified as sulfur oxides, nitrogen oxides, organics, and particulates. Basic toxicology and population studies as well as clinical research involving human subjects all play important roles in the development of the basis for environmental standards. The following discussion focuses on the contribution of clinical studies, however.

Clinical studies in EPA have evolved in two parallel phases. Phase I is the establishment and maintenance of a clinical studies research facility and the development of new techniques with which environmental conditions can be simulated and their effects assessed. This developmental activity is necessary because of the relative lack of prior work in Clinical Environmental Research. EPA has assumed a leading role in developing this area of investigation. Phase II is the actual use of those resources in conducting studies. The energy R&D effort has a role to play in both phases of the EPA's clinical studies program. In Phase I the energy program provides the data quality assurance for components of the research system. In Phase II it funds outside independent studies similar to those being conducted in-house by EPA.

EPA CLINICAL STUDIES

The Environmental Clinical Studies within EPA centers on the Clinical Laboratory Evaluation and Assessment of Noxious Substance (CLEANS) facility located at the University of North Carolina in Chapel Hill. A product of several years of design and development, this facility is now complete, and testing of energy related pollutants will begin shortly. In addition to the CLEANS facility, two mobile physiology laboratories using the same data acquisition system are available to conduct studies in populations exposed to effluents of alternate energy production. Finally, a prototype Controlled Environmental Laboratory equipped for producing atmospheres containing ozone, nitrogen dioxide, carbon monoxide, and sulfuric acid aerosol has been in use since July 1974.

The CLEANS project includes an on-line computerized physiologic data acquisition system serving two Controlled Environment Laboratories (CEL's). Because of the complexity of instrumentation associated with CLEANS, as well as the large amount of data which can be acquired, most measurement is under computer control. In the CEL's human subjects are exposed for extended periods of time to similar pollution levels found in urban areas or areas adjacent to energy sources. The CLEANS laboratories allow researchers to perform experiments addressing a wide range of physiological responses. Especially important in each CEL are the instruments for measuring the functioning of heart and lungs before, during, and after exercise. In addition to evaluation of cardiopulmonary status, studies of immune mechanisms, hematologic and metabolic parameters, and neurobehavioral function are conducted in these subjects.

Studies are now in progress to determine the effects of sulfuric acid aerosol on healthy subjects. Depending on the results of this research, other studies will be designed to assess the effects of ammonium bisulfate and ammonium sulfate. The sulfate research, just beginning, is especially important and timely. Many forms of sulfates result either directly or indirectly from all fossil fuel fired combustion sources. For example, EPA currently estimates that the peak atmospheric burden of sulfuric acid aerosol is in the range of 20 $\mu g/m^3$. The widespread increase of coal combustion, necessitated by our national energy policy along with the increased use of oxidative catalytic converters on automobiles, may result in atmospheric sulfate levels four times higher than those measured now.

DATA QUALITY ASSURANCE

In Phase I support of EPA's Clinical Studies of H_2SO_4, the energy program is currently providing independent audits of atmospheres generated in the CLEANS system. The CEL's have technically complex computer controlled systems for simulating a polluted environment. The most complicated component of the CEL's environmental control system is the aerosol generating and measurement equipment. This equipment must be continuously calibrated and monitored for accuracy in order to assure the integrity of the research as well as the safety of the human subjects.

Adequate definition of the relationship between aerosol exposure and the various measurements of health status depends on many factors in the experimental setting. Most important among these are provisions for continuous production of well characterized aerosol atmospheres using a variety of specific chemical compounds over a range of mass concentrations and droplet sizes. These conditions must be predictably created at various combinations of temperature and relative humidity and in the presence of various gaseous pollutants as well as in clean air. Finally, these atmospheres must be generated in a controlled laboratory large enough to accommodate the human subjects and the physiology instrumentation for long periods of time. Assembly of the aerosol generating and control equipment to accomplish a task of this magnitude and complexity has never before been attempted. The engineering design and development for this program has been done and construction of the aerosol facility is now in progress. Throughout all phases of this project, the Energy R&D Program has contributed support in a major way.

IN-HOUSE AND EXTRAMURAL STUDIES

At present there is no standard for sulfates or for acid aerosols. With the anticipated increased use of coal, the need for such a standard is now even more pressing than before. Sulfuric acid aerosol studies in the range of 50-200 $\mu g/m^3$ with particle size in the range of 0.1 to 0.5 microns now being conducted are essential first steps in providing a data base which is necessary for the development of a regulatory strategy for all sulfur oxide aerosols. The CLEANS studies on effects of H_2SO_4 aerosol inhalation in humans involves three parallel efforts, two by grantees and one in-house. The energy program is providing supplemental support to the CLEANS study of H_2SO_4 by providing the two independent studies.

The protocol for EPA's in-house program calls for the evaluation of healthy young men between the ages of 19 and 30. After entrance to the exposure chamber a subject will be exposed to H_2SO_4 for 2 hours. The initial study will focus on a concentration of 100 $\mu g/m^3$ and particle size of 0.05 to 0.5 microns. In order to assess the possible immediate effects, tidal volumes will be measured every five minutes initially and complete pulmonary function testing every 15 minutes. There are two 15-minute periods of moderate exercise during the exposure to simulate a reasonable level of activity. In addition to the pulmonary function tests, a standard battery of blood chemistry analyses, evaluation of immune mechanisms, karyotyping, and assessment of olfactory perception will also be done.

Despite the level of effort associated with CLEANS, it is absolutely necessary that independent studies also be conducted outside of EPA. Such supplemental studies help verify the results of CLEANS and add to a data base broad enough to assess the effect on human health of sulfate aerosols for regulatory purposes.

The first study provided for under the energy program is being conducted by the University of Maryland, School of Medicine. During the first year the Maryland group plans to study 30 normal healthy males utilizing a double blind 3-day protocol. The study will use a one 4-hour exposure to 100 $\mu g/m^3$ of acid aerosol with a particle size of 0.1 to 0.3 microns. Pulmonary function will be evaluated before exposure, at the end of 2 hours of exposure, at the end of 4 hours of exposure, 2 hours after completing exposure, and 20 hours after completing exposure. The Maryland work augments, especially through the use of different exposure times, experiments being conducted by EPA.

The second project supported by a grant from the Energy R&D Program is also examining the effects of exposure to H_2SO_4 aerosols in humans. This work, to be conducted at the University of California, considers other important factors affecting toxicity, such as temperature, humidity, and duration of exposure. In this study subjects will be exposed in an environmental chamber to either filtered air, 400 $\mu g/m^3$ or 800 $\mu g/m^3$ of H_2SO_4 under four conditions of temperature and humidity. They are 18°C-45%RH; 35°C-85%RH; 35°C-45%RH; and 35°C-88%RH. Particle sizes will be approximately 0.3 microns. Subjects will exercise intermittently at 25% of their maximum capacity during the exposure period. Pulmonary function tests will be performed before, during, and after exposure. Cardiovascular performance will be assessed during the exposure and exercise periods.

CONCLUSION

EPA Health Effects Research Program will continue to pursue a broad based, multidisciplinary research program, a large part of which will identify and quantify health consequences of changing energy production technology. It is clear that tighter homes and a shift to more coal combustion is occurring in this country. Therefore a larger clinical studies program addressing sulfur oxides, heavy metals, organics, and indoor pollution is indispensable.

The completion of the CLEANS facility has provided health researchers with an important resource for assessing human exposures more accurately and for longer durations than in the past. Research is in progress to evaluate effects of carbon monoxide, oxidants, and sulfates. New studies will address nitrogen oxides and other aerosols such as nitrates. These studies will be an important feature of the Nation's energy program.

CURRENT STATUS OF EXTRAPOLATION RESEARCH

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INTRODUCTION

Since relevant human data on the carcinogenic potential of various chemicals found in man's environment are generally not available, society is being forced to place increasing reliance on animal experimentations for establishing guidelines by which human risk can be estimated. In estimating human risk from data generated in a laboratory setting, two major problems must be confronted. The first involves the extrapolation of effects observed at high, often maximum tolerated dose levels typically employed in laboratory experiments to the low environmental levels to which man is exposed. Then, when this extrapolation has be completed, there is the equally difficult problem of the conversion of the risk estimates for animals at environmental exposure levels to corresponding estimates for man.

One of the first attempts to address the issue of low dose extrapolation was a probit-type model proposed by Mantel and Bryan in 1961. Although it has been used in the regulatory decision making process, it suffers from the drawback of being generated on an empirical basis and of lacking a strong biological justification. During this same period a number of mathematical models relating time-to-tumor occurrence rather than tumor incidence to dose were introduced. Unfortunately, technical complications arising in the estimation of unknown parameters have often prevented the widespread usage of these various models. In 1975 a HEW Subcommittee on Estimation of Risks of Irreversible, Delayed Toxicity recommended the adoption of a linear extrapolation model as an interim procedure for risk estimation.

The question of species-to-species extrapolation possibly has been even more frustrating to researchers than the question of low dose extrapolation. Extrapolations from animal test systems to man have generally tended to ignore quantitative aspects of species differences in absorption, metabolism, and excretion. At best, some sort of attempt is usually made to establish species equivalency in the administered dose levels, and an additional safety factor reminiscent of standard toxicity testing may also be employed.

This paper attempts to summarize some of the results that have been obtained from research on the various issues cited above that have been totally or partially initiated under the Interagency Energy/Environment R & D Program.

LOW-DOSE EXTRAPOLATION

Guess and Crump have developed a new statistical model for predicting the risk associated with continuous exposure to a direct-acting carcinogen (i.e., a carcinogen effecting cellular DNA directly) at low, environmental levels using high dose level animal data. The model, which is based on Doll and Armitage's multistage representation of the carcinogenesis process, is general enough to reflect both linear responses associated with the one-hit model as well as the non-linear responses characterized, e.g., by the probit-type models. Using this model Guess and Crump analyzed a variety of data sets generated from animal experiments that had previously established the carcinogenicity of such compounds as dimethylnitrosamine, vinyl chloride, and chloroform. By combining the results of these analyses with those obtained from various simulation studies the two investigators were able to reach several conclusions that have important bearing on the general issue of low-dose extrapolation.

According to Guess and Crump most of the tested carcinogens appear to behave in a linear (or nearly linear) fashion at low dose levels, even if they exhibited a non-linear response in the experimental dose range. They also demonstrated that tight confidence limits for the point estimate of risk at low dose levels can usually be established for compounds that exhibit a strong linear trend in the experimental dose range. Finally, it seems that if there is a non-zero background incidence of the specific cancer of interest in the animal test system under investigation, even a very large-scale animal study is unlikely to be able to establish a no effect or threshold region in the low dose range. One of the most important implications of these findings is that for many direct-acting carcinogens there may be little likelihood of establishing a human exposure level that will have an estimated risk as low as (or lower than) 10^{-6} and, at the same time, will enable the compound to be usable as a food additive from the point of view of economic feasibility.

In a related work, Jerzy Neyman has focused on the specific problem of estimating the public health hazards associated with electricity-producing nuclear generators. Neyman notes that much of the current effort to estimate the carcinogenic risk associated with environmental level exposures is based on extrapolations from high dose level animal experiments and/or historical human data such as those obtained from the various investigations of the Nagasaki and Hiroshima survivors. He seriously questions the utility of these types of extrapolations, since he feels that the results are often confounded by failure to properly account for competing risks, dose-rate (as opposed to dose) dependencies, and species differences in the case of laboratory based extrapolations. As an alternative he advocates the use of large scale epidemiological studies conducted in a variety of different geographic settings for establishing estimates of human risk. While the objections which Neyman has raised to extrapolations using laboratory animal data certainly need to be given careful consideration, it does not seem practical to abandon these calculations solely in favor of the epidemiological studies he is advocating. In many instances such studies would not be feasible. Even when they can be performed it is not immediately obvious that they will always be able to generate data that is sufficiently sensitive to establish "acceptable" or "safe" irradiation exposure levels. The more realistic strategy may be to use both types of studies whenever possible in the decision making process, while continuing to attempt to improve the methodology associated with each.

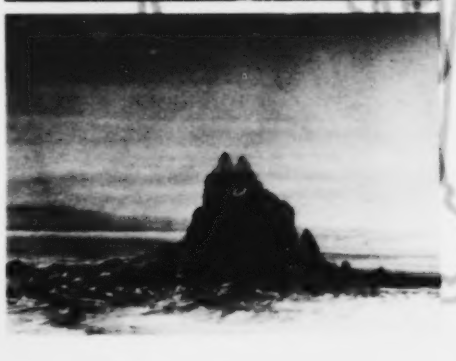
SPECIES-TO-SPECIES EXTRAPOLATION

While investigations of the species-to-species extrapolation issue have also been sponsored under the Interagency Energy Agreement, most of the work is still in progress and relatively few results have been obtained to date. A contract for reviewing the published carcinogenesis literature in order to establish a data base of chemicals that have displayed positive responses in at least two species has been initiated. The major goal of this contract is to use this data base to make quantitative extrapolations between species for which reliable cancer data exists. In the extrapolation process attempts will be made to account for factors modifying the effect of dose in cases where substantial differences exist. The literature review of the various compounds known to be carcinogenic in man as well as one or more animal species has been completed, and the analysis of the aflatoxin data is in its final stage.

In addition to the literature based study cited above, partial funding is also being provided to a large scale study of the pulmonary effects of environmental oxidant pollutants. While the main focus of the grant is on the mechanisms underlying the harmful effects of exposure to high ambient levels of ozone and the adaption process following this exposure, comparison of the effects observed among different rodent species and nonhuman primates should provide insight into ways of improving extrapolations of potential long-term, deleterious effects of photochemical smog on man. During the current year studies in various animal species of adaption to acute and subchronic ozone exposures were instituted, and the usefulness of expired ethane and pentane as indices of lipid peroxidative damage were conducted.

Although almost all of the emphasis in species-to-species extrapolation research has been on carcinogenesis, other disease endpoints are beginning to receive long overdue attention. As part of this effect, support has been given to the creation of a computerized reference system for teratological literature. This Environmental Teratology Information Center (ETIC), which is being developed by Dr. Robert Staples of NIEHS, is located at the Oak Ridge National Laboratories. During the past year over 7500 references have been introduced into the system. Attempts to construct a Teratology Data Bank have also been instituted. Eventually these two computer information systems may provide the vehicle by which the question of species differences in response to teratogenic exposures can be systematically evaluated.

atmospheric transport and fate



CHAPTER 7

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atmospheric transport and fate

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ATMOSPHERIC TRANSPORT AND FATE

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INTRODUCTION

I am serving as both author of a paper on Project MISTT (Midwest Interstate Sulfur Transformation and Transport) and rapporteur.

I do not need to say much about the reasons for concern with sulfate. The possible health effects and numerous ecological effects will be discussed throughout this meeting.

The technical approach of the project MISTT study is to investigate the transformations of SO_2 to sulfate in polluted air masses undergoing transport. Our original plan was to study power plant plumes and urban plumes. During the program, we became aware of the stagnating anticyclone, another air mass that undergoes transport and in which transformations occur. In stagnant air masses, pollutants build up and are then transported as the weather system moves.

FOUR TYPES OF RESULTS

In this symposium we are expected to emphasize results. Project MISTT produced four types of results—those relating to (1) reaction rates and mechanisms, (2) plume study techniques, in which we have made some advances, (3) transport distances over which pollutants can move, and (4) development of models. My MISTT paper is followed by a bibliography of 15 published scientific articles on Project MISTT; 15 presentations to national and international scientific meetings, which will ultimately be published; and 20 papers that will be presented in Dubrovnik, Yugoslavia, in September at the International Symposium on Sulfates in the Atmosphere. Although we are just entering the third year of Project MISTT, we do have some results to report. I am going to move rapidly through a series of slides to give you an appreciation and a flavor of the program and of the results we are obtaining. I do not expect you to absorb all the details of these figures.

The Labadie Power Plant plume outside St. Louis is our favorite case study (Figure 1). In the middle of the day the plume rapidly dilutes and mixes with ambient air. When we first started this program, we decided to follow plumes for 60 kilometers. Some very noted scientists and meteorologists laughed at us and said, "No way can you follow a plume for 60 kilometers." But sometimes we can follow them much farther.

Figure 2 shows Labadie early in the morning. The plume does not mix rapidly with the atmosphere because of the stable atmospheric conditions that normally exist at night.

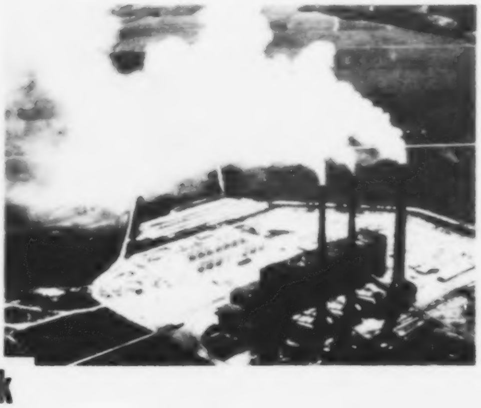

Figure 1.
Labadie plume, well mixed

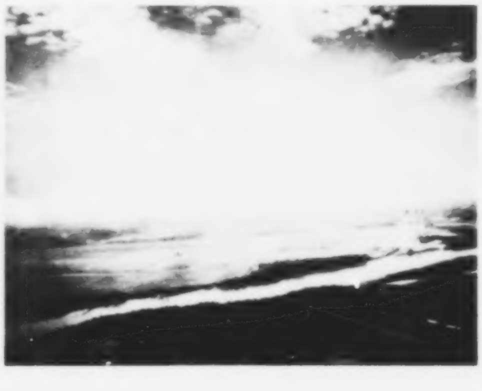

Figure 2.
Labadie plume, not well mixed

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Figure 3 shows Labadie farther back. Although there is some expansion of the plume immediately after it leaves the power plant, it does not expand much more as it goes downwind. We followed this plume for 300 kilometers, and it was still going strong when we ran low on gas. At 300 kilometers it was not much wider than at 25 or 30 kilometers.

Figure 4 shows the type of measurements that are made. We fly a sampling airplane back and forth through the plume, obtaining profiles of a large variety of pollutants within the plume. We also measure a vertical profile by spiraling down through the plume, thus obtaining a three-dimensional cross section of the pollutant concentrations. We use pilot balloons to measure wind direction and speed as a function of altitude. With this information we can construct the mass flow rates of pollutants along a plane through the plume. Using mass flow rates is an improvement over earlier work using SO_2-to-sulfate ratios because we can better account for removal of SO_2 by the ground and leakage of SO_2 through the inversion layer.

Figure 5 shows the results we got. Note the location of St. Louis and the various power plants and refineries. Profiles of SO_2 at various distances downwind were measured by our instrumented aircraft. As we start out, the plume is very narrow. As we move downwind, it broadens out. This plume was followed out to 140 kilometers during 14 hours of flight time.

Figure 3.
Labadie plume, farther back

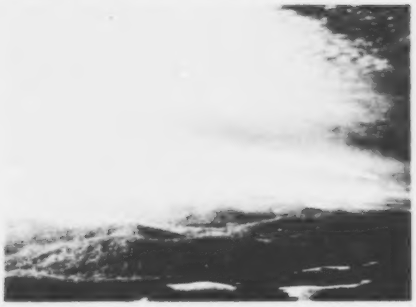


Figure 4.
Plume mapping program

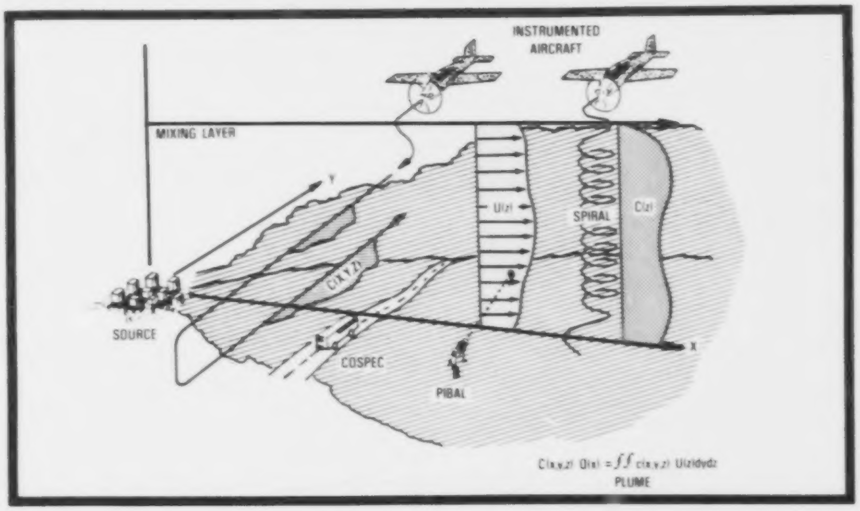
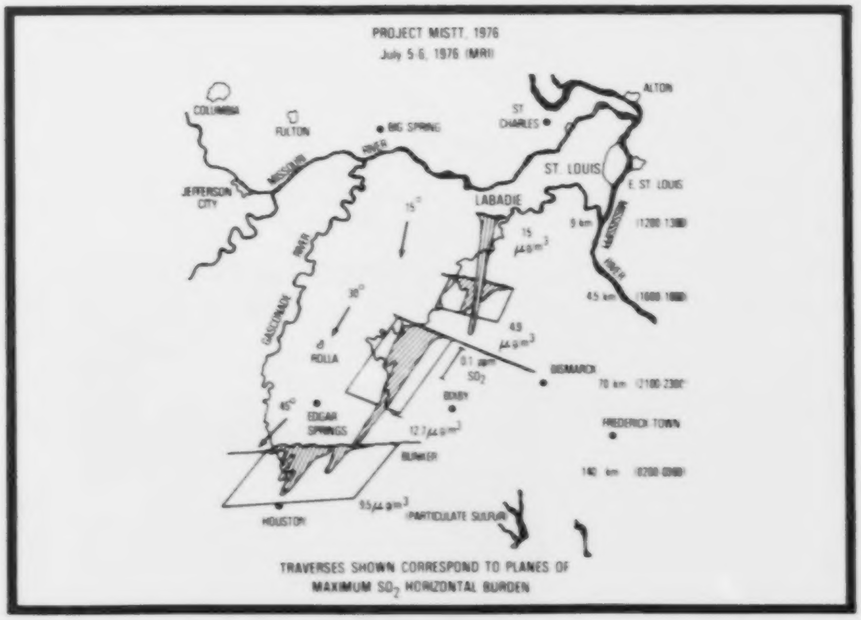

INSTRUMENTED
AIRCRAFT
MIXING LAYER
Y
U(z)
SPIRAL
C(z)
C(X,Y,Z)
SOURCE
COSPEC
PIBAL
X
C(x,y,z) Q(x) = ∫∫ c(x,y,z) U(z)dydz
PLUME

Figure 5.
Sulfate measurements


PROJECT MISTT, 1976
July 5-6, 1976 (MRI)
COLUMBIA
FULTON
BIG SPRING
ST CHARLES
ALTON
MISSOURI
RIVER
JEFFERSON CITY
ST. LOUIS
E. ST. LOUIS
LABADIE
MISSISSIPPI
RIVER
15°
15 μg/m³
9 km (1200-1300)
4.5 km (1600-1800)
GASCONADE
RIVER
30°
ROLLA
4.9 μg/m³
0.1 ppm SO₂
BISMARCK
70 km (2100-2300)
BIXBY
45°
EDGAR SPRINGS
12.7 μg/m³
FREDERICK TOWN
BUNKER
140 km (0200-0300)
9.5 μg/m³
(PARTICULATE SULFUR)
HOUSTON
TRAVERSES SHOWN CORRESPOND TO PLANES OF
MAXIMUM SO₂ HORIZONTAL BURDEN

SULFATE MEASUREMENTS

Sulfate measurements were also made. The squares, in Figure 5, indicate the sulfate integrated over a flight segment. A new supersensitive technique for sulfate was developed for aircraft use in this program. This technique enabled us to collect enough sulfate in one pass through a plume to get a valid sulfate measurement. We very often see this type of plume coming from St. Louis.

We also measured the detailed size distribution and calculated the aerosol volume. Figure 6 plots the aerosol volume flow rate for several different studies as a function of the age of the plume, out to only 2 hours. We found differences depending on the time of day and the distance. Our 1974 work showed a rate increase as we moved farther down the plume. This may be due to more sunshine, more mixing, or both. The reaction rates in the plume vary greatly from day to day and from point to point. One problem is to untangle the parameters which control these rates.

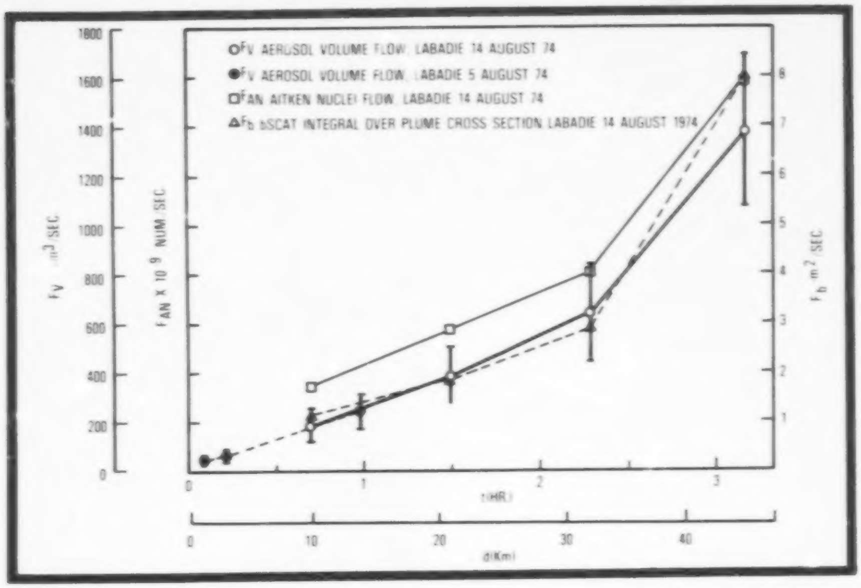


Figure 6.
Aerosol volume calculated

Solar radiation is important in determining the amount and rate of conversion of SO_2 to sulfate. For two runs we plotted for 2 days the percent of SO_2 removal. We show the loss to the ground of SO_2, and the conversion of SO_2 to sulfate. Sunlight is clearly an important parameter. Earlier work on conversion of SO_2 to sulfate in power plant plumes utilized the cohesive plume that exists early in the morning or late at night. This was partly because it was necessary to collect large amounts of SO_2 and sulfate in order to make measurements. As a result, most workers obtained very low conversion rates, partly because there was less sunlight early in the morning and late in the afternoon, and less mixing with the background air that brings in ozone and other reactive species to augment the reaction.

HOMOGENEOUS AND HETEROGENEOUS REACTIONS

Our results suggest the existence of both homogeneous and heterogeneous reactions. Homogeneous reactions, which probably involve the hydroxyl radical, predominate in dry daylight conditions. The rates vary from 1/2 to 5 percent per hour, depending on sunlight intensity, water vapor concentration, ozone concentration in the background air, background pollution levels in general, and the extent of mixing of the plume with background air. Homogeneous reactions and rates are similar to those found in smog chambers. We have a good understanding of homogeneous reactions.

Heterogeneous reactions involving liquid droplets may predominate during high relative humidity, at night, and in clouds. These rates may be much higher than the 1/2 to 5 percent for homogeneous reactions. We do not have good quantitative data on this yet, but we know that with very high sulfate and very high conversion rates, we have liquid droplets. Either clouds are present, or relative humidity is high at night.

The key parameters are ozone in the background layer, ammonia which neutralizes sulfuric acid in the droplets, thus keeping the reaction going, catalytic species, water vapor, and mixing with background air. We are concerned with the reaction mechanisms because they will determine the amount of control needed, according to Dr. Perhac's EPRI paper.

The homogeneous reactions are first order in SO_2; for example, if we want 80 percent reduction in sulfate, we think in terms of 80 percent reduction in SO_2. The heterogeneous reactions are not first order in SO_2. The order is lower; in some cases, perhaps even zero order. Let us assume, as some sort of average, that 10 percent of SO_2 is converted to sulfate. If we want an 80 percent decrease in sulfate and the mechanism is zero order, we would have to reduce SO_2 emissions by 98 percent. The chemical mechanism, then, can make a big difference in the amount of control needed. We are, therefore, devoting substantial effort to determining reaction mechanisms.

Because we expect heterogeneous reactions at night, we studied plumes at night. We had difficulty finding the plume in our 1975 summer work. In 1976 we had LIDAR facilities help us locate the plume to learn about its shape and structure, both at nighttime and daytime.

USE OF AIRBORNE LIDAR

Figure 7 shows a shot of the general area where we have a LIDAR vehicle driving back and forth under the Labadie Power Plant plume, about 35 miles from the plant. In the middle of the night the plume is very small and cohesive; as we go back and forth, it shifts around but does not get very big. In the morning as the sunlight warms the ground, mixing begins, and at 9 a.m. to 10 a.m. there is a breakup of the inversion. At this time the plume spreads out a great deal. EPA Las Vegas used an early version of an airborne LIDAR to help locate the plume and vector the sampling airplane into the plume.

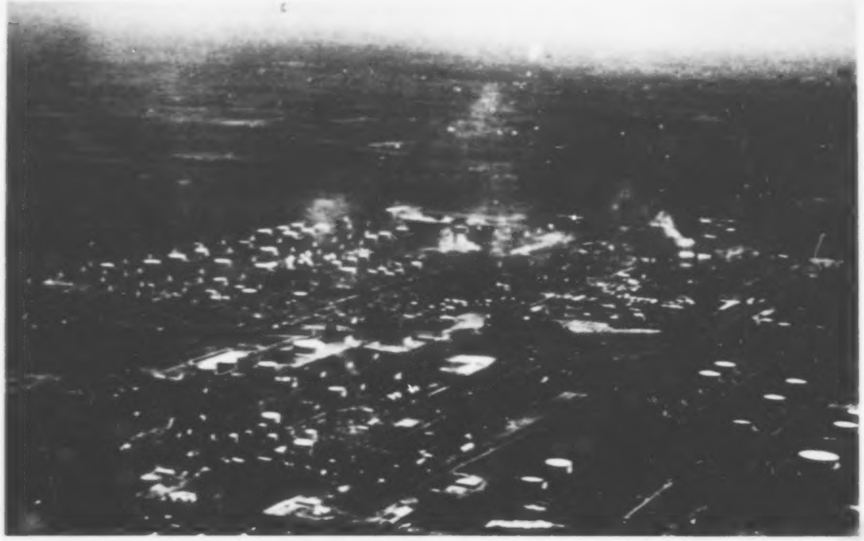


Figure 7.

Labadie plume at Wood River

Figure 8 shows how plume shapes differ. These shots were all taken late in the evening. The largest plume was emitted at 1 p.m. about 50 kilometers downwind. A few hours later the plume emitted at 7 p.m. It is much narrower. At the same time we found the much smaller plume emitted at 9:30, which had caught up with the 7:00 p.m. plume. This is due to the nocturnal jet. A much higher air flow that picked up the plume late in the evening carried it along faster than the plume emitted earlier.

IMPROVED TECHNIQUES FOR PLUME STUDY

Let me summarize the improved techniques for studying plumes. We have mentioned how plume structure influences reaction because of the mixing of background air, the importance of measuring mass flow rates instead of concentration ratios, the importance of making direct measurements of sulfate on as fine a time resolution as possible, and the importance of measuring aerosol size distribution. Last week we tried a new technique in a cooperative study with EPRI and ERDA. We are making continuous sulfate measurements in conjunction with continuous tracer measurements. We hope this will prove to be a very useful new technique. As an example of cooperative study, an ERDA national laboratory, Battelle Northwest, under contract to EPRI, is flying plume studies jointly with an EPA contract airplane. We are cooperating very well in this case.

Plumes come not only from power plants but also from large urban areas. The Wood River refinery is north of St. Louis. We can see a very nice plume coming out from St. Louis.

Figure 8 shows the Labadie plume going along next to the plume from Wood River and St. Louis. We can also see that the plume from Portage de Sault power plant gets mixed with the urban plumes and they all go out towards Chicago. We followed this plume about 300 kilometers toward Chicago and had to stop because we got into the Chicago air traffic control district. In this case the Labadie plume is mixed with part of the St. Louis urban plume. This is one of the few cases in which we have seen an ozone bulge in a power plant plume. We do see this occasionally, but only when the power plant plume is mixing with background air that we might expect to be rich in hydrocarbons.

Figure 9 is another example of the plume going out from St. Louis. The darker portion is the light-scattering measured by an integrating nephelometer. The lighter portion is ozone. As we start from St. Louis, the ozone is all below 50 ppb. As we move out, the light scattering increases, due largely to the formation of sulfate aerosol. As we move downwind, the plume does not change greatly in width, but there is an increase in both light scattering and ozone.

Figure 10 graphs measurements of the sulfate at different vertical passes through the plume and at different distances downwind. From this we can integrate and obtain the mass flow rate of particulate sulfur, light scattering, and ozone (Figure 11). These mass flow profiles look very much like the concentration profiles seen in smog chamber studies.

Figure 8.
Plume to Chicago

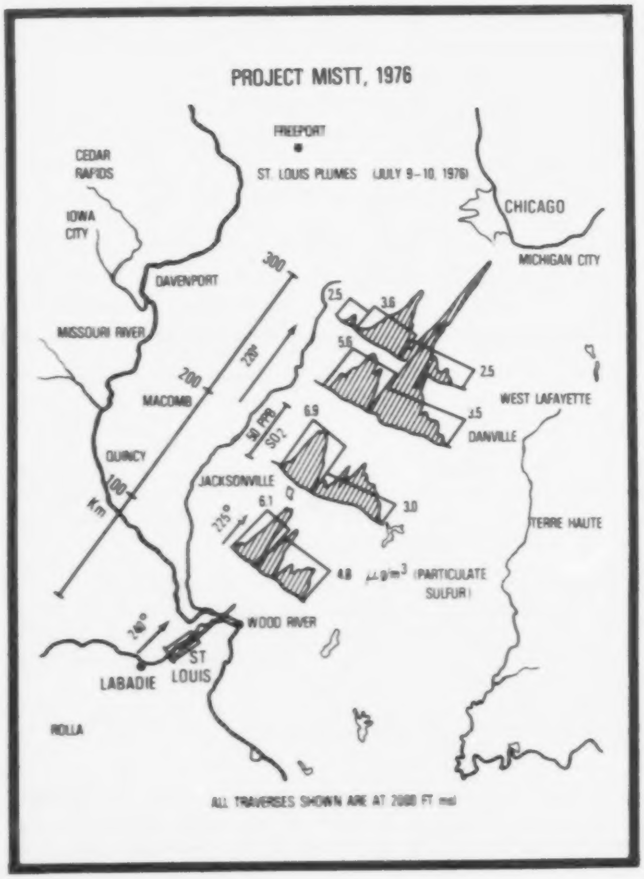

PROJECT MISTT, 1976
FREEPORT
ST. LOUIS PLUMES (JULY 9–10, 1976)
CEDAR RAPIDS
IOWA CITY
CHICAGO
MICHIGAN CITY
DAVENPORT
MISSOURI RIVER
300
200
100
Km
220°
MACOMB
QUINCY
50 PPB SO2
2.5
3.6
5.6
2.5
3.5
6.9
3.0
6.1
4.8
μg/m3 (PARTICULATE SULFUR)
225°
WEST LAFAYETTE
DANVILLE
JACKSONVILLE
TERRE HAUTE
WOOD RIVER
240°
ST LOUIS
LABADIE
ROLLA
ALL TRAVERSES SHOWN ARE AT 2000 FT msl

Figure 9.
Light-scattering and ozone measurements

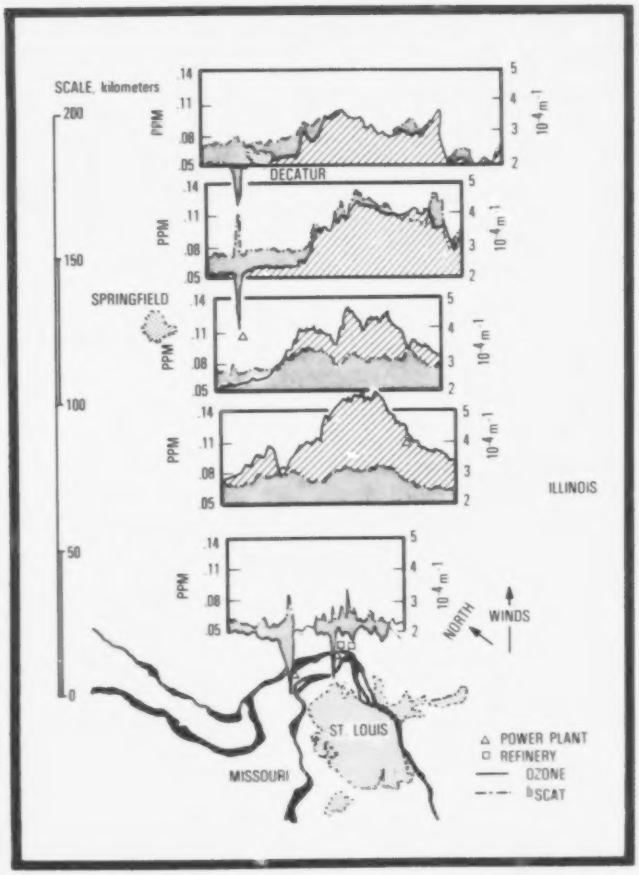


Figure 10.

Sulfate measurement at different passes

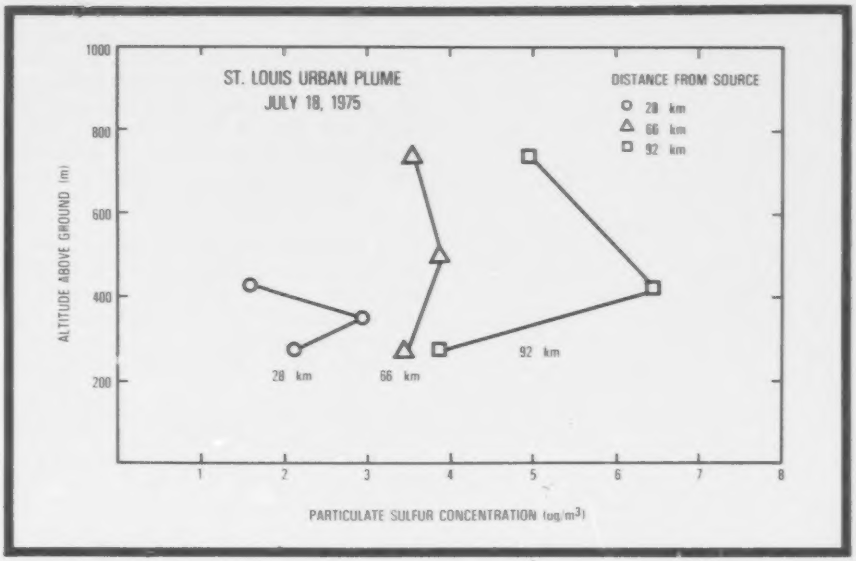
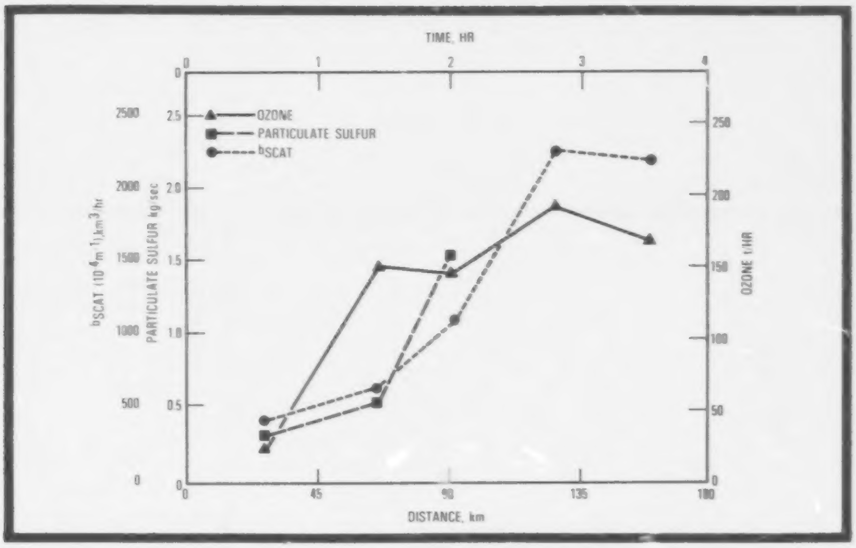


Figure 11.

Mass flow rates St. Louis urban plume



We have also developed models of several levels of complexity. These describe the formation of secondary pollutants in power plant and urban plumes and include mixing, dry deposition, and chemical reaction.

DIFFERENCES BETWEEN SURFACE AND ELEVATED PLUMES

Figure 12 is a simple model showing the difference between a surface plume and an elevated plume. Because the surface plume results in high ground concentrations early in its history, there is more SO_2 loss by ground deposition. A tall power plant plume allows the SO_2 to stay around longer to form sulfate.

The time and distance over which an air mass maintains its integrity will depend on its initial size and on the meteorological conditions. The primary determinant is the amount of wind shear. We have tracked power plant and urban plumes for at least 300 kilometers, and the "blob", or hazy air mass associated with a stagnating anticyclone, has been tracked for hundreds of kilometers.

Figure 13 is a satellite photograph. The light, hazy area, or blob, is due to air pollution rather than clouds.

We can also study blobs by using visibility isopleths taken from the National Weather Service. The next several figures are isopleths of noonday, human-observer, visibility distances. These have been plotted in scattering or extinction, but they represent visibilities of less than 3 miles, 3 to 4 miles, and 4 to 6 miles.

Figure 12.
Surface and elevated plumes

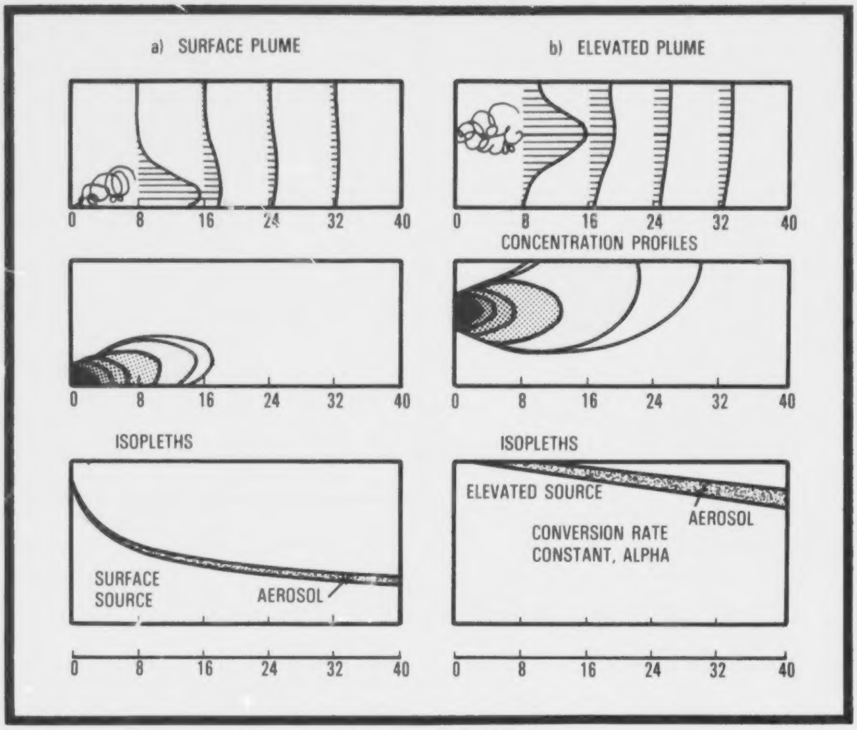


Figure 13.
Satellite picture

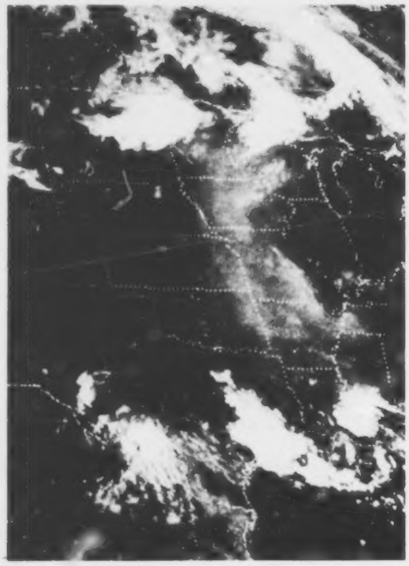


Figure 14 is a satellite shot of a low visibility region building up in the central Ohio Valley area. The next day it intensified. As we watched, it began to move; this particular anticyclone broke up, with one part going toward Canada, another coming down toward the TVA area. It slowed down and broadened out, then moved over across St. Louis and started up again. The shape is in agreement with the shape of the hazy blob from the satellite. This moved on up toward Minneapolis and broke up again. One part went toward Canada, another part came back across the Great Lakes, moved on, and then the winds start blowing it south. It comes down, crosses Birmingham, and then goes out to sea over Jacksonville. So some of the pollution in Jacksonville, Florida, started out 2 weeks earlier in the Ohio River Valley and moved around the country before arriving in Jacksonville. This is borne out by long-range air mass trajectories. In Figure 15 we started with a box around St. Louis and looked at the backward and forward trajectories. This agrees well with the visual expectation from just looking at the various slides of the visibility profiles.

In addition to the scientific results, we have some policy results that are at least worth consideration. Sulfate, generated from SO_2 and power plant and urban plumes, and ozone, generated from hydrocarbons and nitrogen oxides in urban plumes, may be transported at least hundreds of kilometers and cause air pollution far from the source.

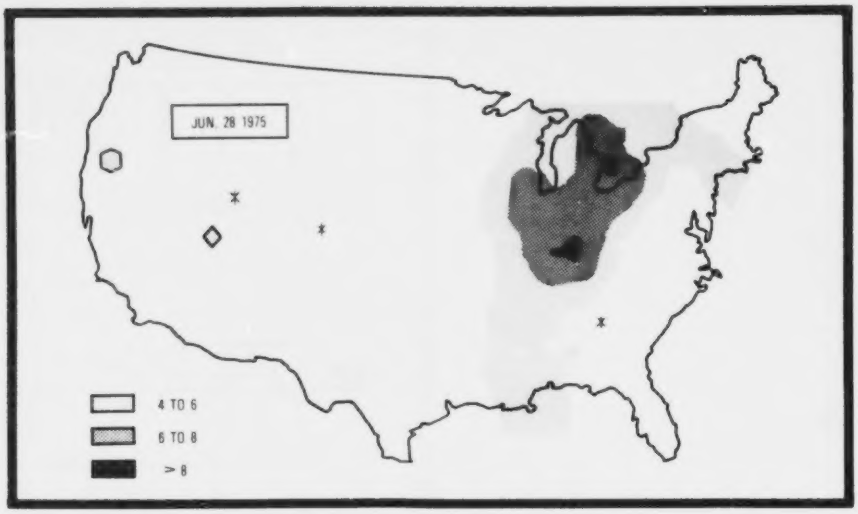
Air pollution resulting from long-range transport of secondary pollutants cannot be controlled by the political entity where the air pollution impact actually occurs. Therefore, our current concept of an air quality control region must be changed in order to take account of the long-range transport of secondary air pollutants.

The future work is aimed toward understanding heterogeneous conversion processes, the dynamics of the blob, and obtaining more statistical information on rates, mechanisms, and plume behavior. We also want to expand our coverage to include gaseous and particulate nitrates and organic material, as well as sulfates and ozone.

PRINCIPALS IN PROJECT MISTT

The principals in Project MISTT have been Stephen Gage, who coordinates the Energy/Environment R&D Program: myself, as Project Director for MISTT; Rudolph Husar of Washington University, who serves as Field Director and Data Manager; Donald Blumenthal of Meteorology Research, Inc., who is responsible for most of the aircraft operations; and Kenneth Whitby of the University of Minnesota, responsible for aerosol measurements and data interpretation. Another 15 organizational units participate in project MISTT.

Figure 14.
Ohio Valley anticyclone


JUN. 28 1975
4 TO 6
6 TO 8
> 8

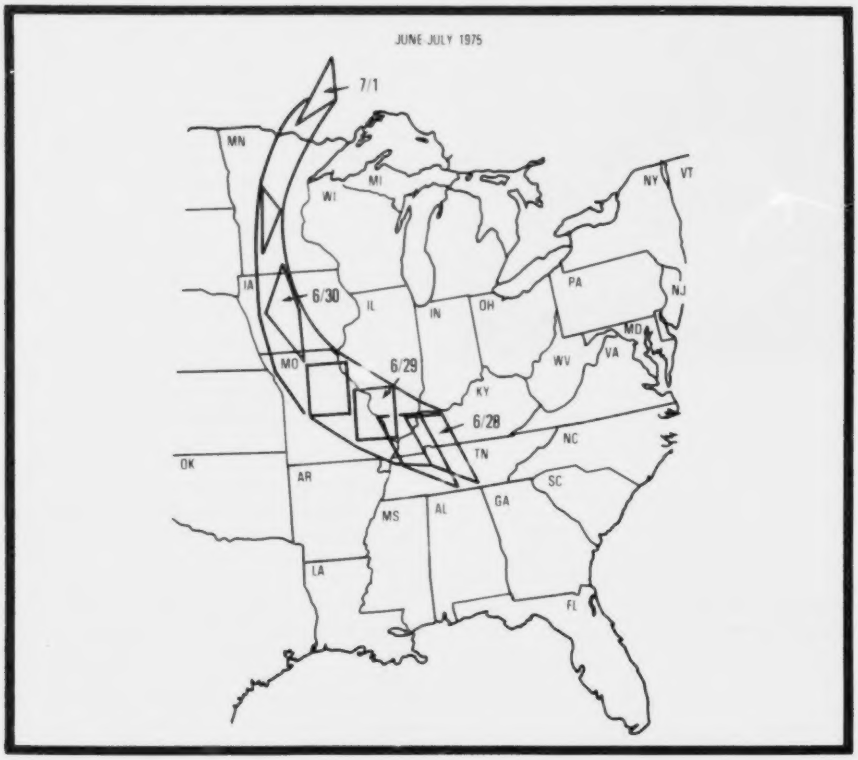
Through the Interagency Program, work is supported at two other agencies. One is an agreement with NOAA to study cloud condensation nuclei formation in western power plant plumes. Rudolph Pueschel is the principal investigator; David McNelis is the EPA project coordinator.

CLOUD CONDENSATION NUCLEI

We are interested in changes in cloud condensation nuclei (CCN), because these can lead to changes in many weather situations—frequency of cloud formation, cloud stability, and rainfall frequency, intensity, and acidity.

Some of the older power plants have visible plumes. In these cases, the fly ash which escapes the control devices will become coated with sulfuric acid and act as CCN's. The newer plants, with more efficient controls, emit very small amounts of fly ash and have nearly invisible plumes. In these cases, the SO_2 which is in the plume will undergo gas-to-particle conversion and form cloud condensation nuclei.

Figure 15.
St. Louis long range air mass trajectories

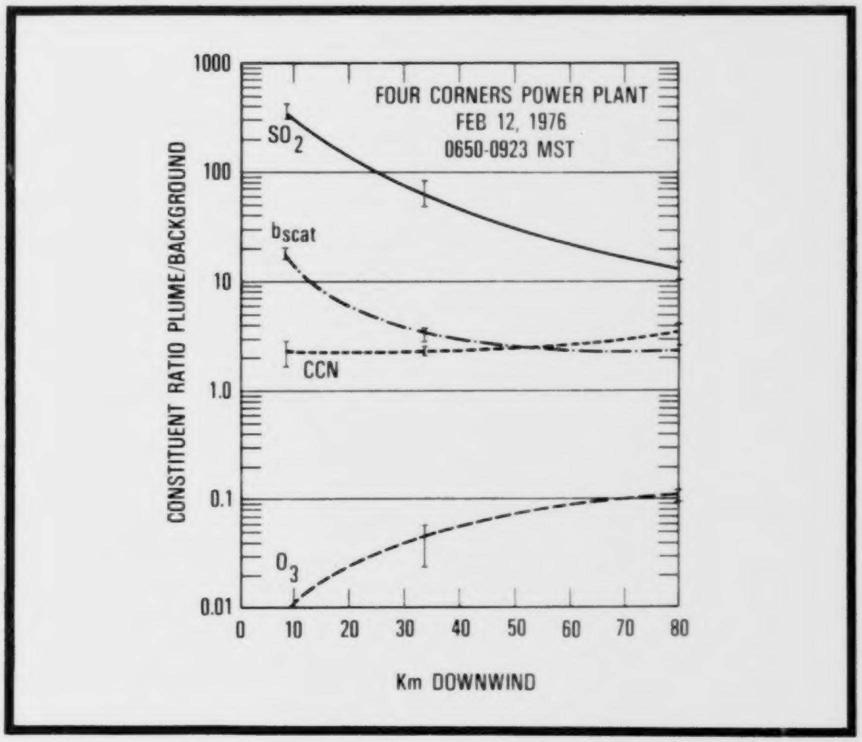

JUNE JULY 1975
7/1
6/30
6/29
6/28
MN
WI
MI
NY
VT
IA
IL
IN
OH
PA
NJ
MD
WV
VA
MO
KY
NC
TN
OK
AR
SC
MS
AL
GA
LA
FL

PLOT OF DATA RECEIVED

Figure 16 is one plot of the type of data that Mr. Pueschel has gotten. The light scattering falls off, but the CCN count is increasing, up to four or five times background; and in the area impacted by the plumes, the power plant will contribute the same order of magnitude as the natural environment, so this may have an influence on weather and climate. These measurements were made in morning flights. The plume probably still contained NO, since the ozone concentration did not get back up to background level. If the plume had been followed longer or observed later in the day, an even larger increase in CCN might have been observed.

In addition, there is interagency agreement with the Tennessee Valley Authority to study the transport and transformation of sulfur oxides in the Tennessee Valley region. J. F. Meagher and Vinaya Sharma are the principal investigators; I am the project coordinator. The TVA program has three parts. Plume studies similar to those in MISTT are being conducted in the TVA area. They have looked at SO_2 conversion during fall and winter conditions and found it to be low, even though we might expect heterogeneous conversion processes to be important then. They are also building a stack-gas smog chamber in which photochemical reactions will be studied with material fed directly from a large power plant stack. In this study, ambient air and actual stack gases will be used to look at the photochemistry of power plant plumes. They are also doing box budget studies in which they are looking at the increase in SO_2 and sulfate across the Tennessee Valley area. In the winter study that has been completed, they found a 25 percent increase in sulfate as the air mass crossed the TVA region. Another study is going on now.

Figure 16.
SO_2 and CCN flux calculations

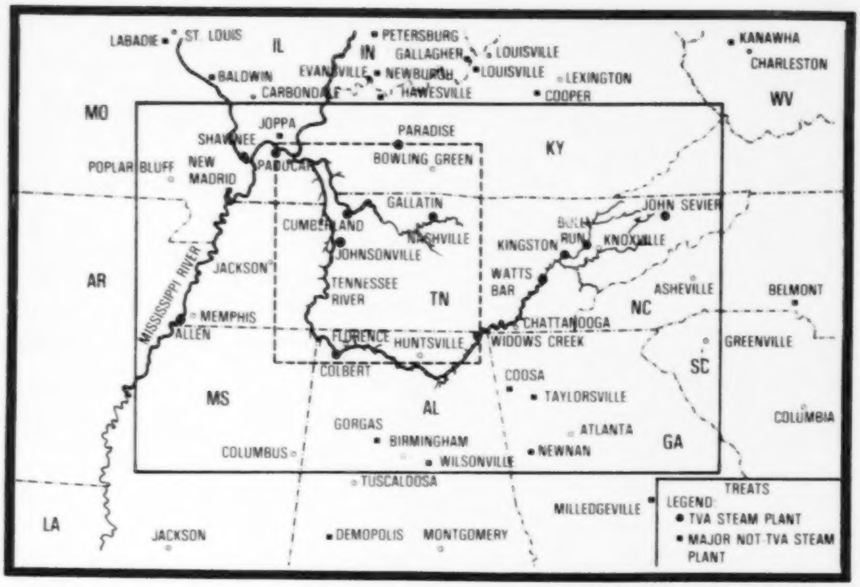


TVA REGION

Figure 17 is the TVA region, showing a number of large power plants. When the wind is from the south, they will do a set of traverses at the bottom of the box in the center of the map and another set of coordinated traverses at the top of the box. They will look at the same air mass and get box budget data, which people have been trying to do for a long time.

There are two more papers in this session, one by Dr. Ralph Perhac of the Electric Power Research Institute, and one by Dr. Michael MacCracken, Lawrence Livermore Laboratory, for the ERDA program. I want to emphasize that these programs are not funded by the Energy/Environment R&D Program, but we have included them in the discussion because they are coordinated with the interagency energy/environment studies. First I will discuss the paper by Dr. Ralph Perhac, which

Figure 17.
TVA power plants


LABADIE
ST. LOUIS
IL
PETERSBURG
IN
GALLAGHER
LOUISVILLE
BALDWIN
EVANSVILLE
NEWBURGH
LOUISVILLE
LEXINGTON
CARBONDALE
HAWESVILLE
COOPER
KANAWHA
CHARLESTON
WV
MO
JOPPA
SHAWNEE
PARADISE
POPLAR BLUFF
NEW MADRID
PADUCAH
BOWLING GREEN
KY
GALLATIN
JOHN SEVIER
CUMBERLAND
BULL RUN
KINGSTON
KNOXVILLE
NASHVILLE
JOHNSONVILLE
AR
JACKSON
MISSISSIPPI RIVER
TENNESSEE RIVER
TN
WATTS BAR
ASHEVILLE
BELMONT
MEMPHIS
ALLEN
NC
CHATTANOOGA
FLORENCE
HUNTSVILLE
WIDOWS CREEK
GREENVILLE
COLBERT
COOSA
SC
MS
TAYLORSVILLE
AL
COLUMBIA
GORGAS
ATLANTA
BIRMINGHAM
GA
COLUMBUS
WILSONVILLE
NEWNAN
TUSCALOOSA
TREATS
MILLEDGEVILLE
LEGEND:
● TVA STEAM PLANT
■ MAJOR NOT TVA STEAM PLANT
LA
JACKSON
DEMOPOLIS
MONTGOMERY

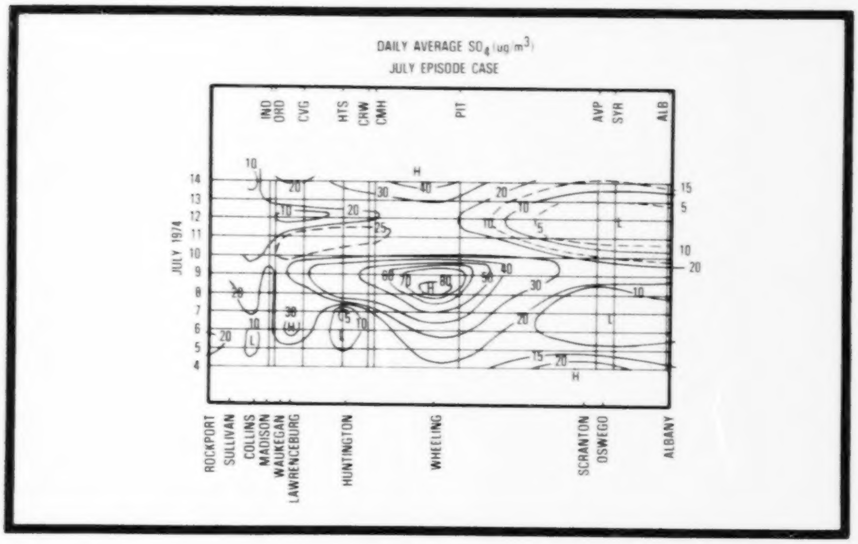
describes the Sulfate Regional Experiment (SURE), a very large project funded by the Electric Power Research Institute. Its two primary purposes are to define ambient sulfate in terms of local SO_2 emissions and to assess the contribution of the electric power industry to regional sulfate levels. The main subdivisions of the SURE program are an extensive ground-level measurement network, aircraft measurements of vertical pollutant profiles in the neighborhood of the ground station, modeling to relate SO_2 emissions to regional sulfate concentrations, and a detailed emissions inventory. Both ERDA and EPA are counting on EPRI to provide the emission inventory for our large-scale models.

SULFATE DATA COLLECTED

Before the large SURE program was started, there was a design phase in which a year's worth of sulfate data were collected at 12 stations running across the northeastern part of the U.S. This program found that the sulfate concentrations were more variable than the SO_2 concentrations, that sulfate tended to be high in the summer while SO_2 tended to be high in the winter. It was found that high sulfate concentrations correlated with temperature, dew point, and high-pressure air masses, especially maritime tropical air flows, and that high sulfate concentrations did not correlate with local SO_2 emissions or with continental polar air masses.

Figure 18 is one of the episodes from July of 1974. The various days are plotted on the vertical axis and the ground stations, running from Illinois to New York, on

Figure 18.
High sulfate episode

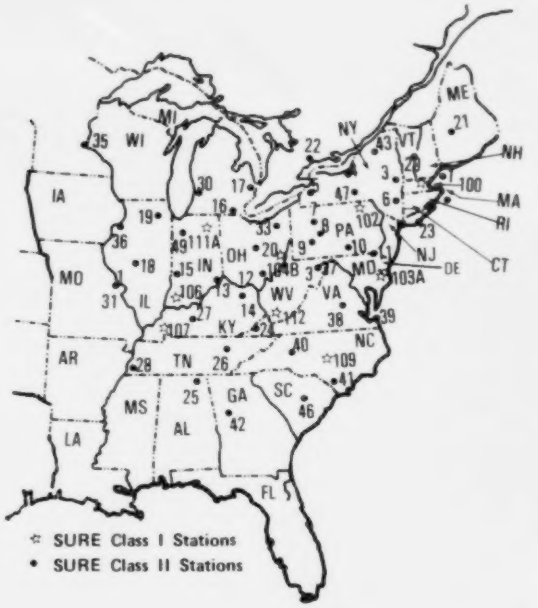


the horizontal. We have isopleths of sulfate concentration. In two instances, sulfate got to 80 micrograms per cubic meter (24-hour-average sulfate) in Wheeling, West Virginia, and another episode when it got up to 70 ug/m^3. We have analyzed this episode at EPA. It appears that the high sulfate levels resulted from transport of sulfates from high emission areas upwind rather than increased local emissions due to stagnation. So this appeared to be a long-range transport episode. I would like to thank EPRI for making these data available to EPA very promptly.

Figure 19 shows the SURE stations. The crosses represent class 1 stations, which will measure a large variety of pollutants year-round. The circles represent class 2 stations, which are part of the regular utility network. These will make additional measurements during intensives, which will take place four times a year.

Figure 19.

Sulfate Regional Experiment ground stations



☆ SURE Class I Stations
• SURE Class II Stations

SURE Class I Stations

100A	Montague, MA
102	Scranton, PA
103A	Indian River, DE
104B	Philo, OH
106	Rockport, IN
107	Giles City, TN
109	Chapel Hill, NC
111A	Roanoke, IN
112	Lewisburg, WV

SURE Class II Stations

1	E. Beverly, MA	24	Loves Mill, VA
2	Fall River, MA	25	Hytop, AL
3	Albany, NY	26	Giles City, TN
4	Oswego, NY	27	Paradise, KY
5	Dunkirk, NY	28	Memphis, TN
6	Roseton, NY	29	Hanover, NH
7	Allegheny, PA	30	Benton Harbor, MI
8	Lewisville, PA	31	St. Louis, MO
9	Brush Valley, PA	33	Niles, OH
10	Gettysburg, PA	35	Madison, WI
11	Delmarva, DE	36	Galesburg, IL
12	Gavin, OH	37	Mount Storm, WV
13	Clifty Creek, OH	38	Chesterfield, VA
14	Big Sandy, OH	39	Yorktown, VA
15	Breed, IN	40	Riverbend, NC
16	Munroe, MI	41	Weatherspoon, NC
17	Port Huron, MI	42	Atlanta, GA
18	Kincaid, IL	43	(Upstate New York)
19	Collins, IL	46	Columbia, SC
20	Picway, OH	47	Cayuga, NY
21	Jay, ME	48	Dan River, NC (?)
22	Toronto, Ont	49	Lafayette, IN
23	Huntington, NY		

EPRI NETWORK

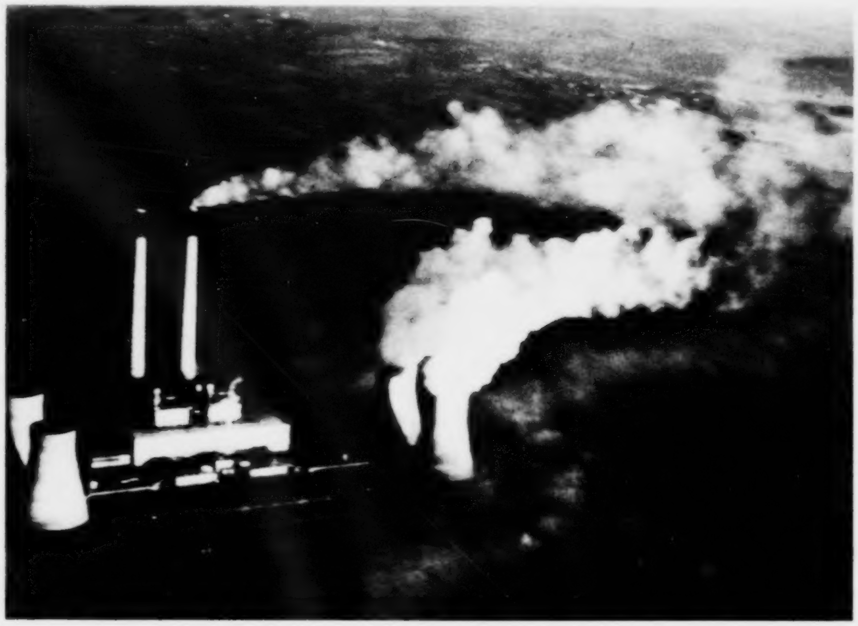
EPA was perhaps fortunate in being able to move their Regional Air Pollution Monitoring Stations (RAMS) from St. Louis into the EPRI network. These stations will benefit the general public by being utilized again, and EPA will have access to the data. EPRI has also kindly let us install a special sampler developed by Florida State University (FSU) which will provide 2-hour measurements of sulfate. To get some idea of the dynamics of the blobs, FSU set up a 14-station network and ran it for 1 year. We are closing that network down now and moving the samplers to the EPRI network. With the FSU samplers, we can collect very cheaply; analyzing is more expensive. We will collect all year and make analysis for a few of the most interesting weeks. It appears that in order to do good modeling, we will need some data with a finer time resolution than 24 hours. EPRI will make 24-hour sulfate measurements year-round, but 3-hour sulfate measurements will be made only during the intensives.

The final paper of this session is by Dr. Michael MacCracken, Director of the Multi-State Atmospheric Power Production Pollution Study (MAP^{3}S), the ERDA sulfate program. The goal of MAP^{3}S is to improve simulation capability for use in evaluating present and future effects due to power production emissions. Their interests are in air quality, precipitation chemistry, and atmospheric behavior. Emphasis is on sulfur oxides from coal combustion in the northeastern United States. The MAP^{3}S program draws on the experience and expertise of several ERDA national laboratories. ERDA also utilizes other scientific organizations via grant and contract funds. There is cooperation and coordination with EPA and other government agencies, with the Electric Power Research Institute, and with the Atmospheric Environment Service of Canada, because there is, of course, transport in both directions across the northern border.

MAP^{3}S TEN TASKS

The MAP^{3}S program is divided into 10 tasks: (1) power plant emissions and (2) other related emissions. These two are fairly small, because we are depending on EPRI for this. (3) A study of pollutant characteristics. ERDA has measurements to determine whether the sulfate is sulfuric acid, ammonium bisulfate, or ammonium sulfate. (4) Pollutant distribution. Aircraft will be flown back and forth across the northeastern U.S. to obtain information on the pollutant distribution. (5) Vertical and long-range transport and (6) pollutant transformation. The rates and mechanism are important. Some of the early work, which demonstrated that the major path for conversion of SO_2 to sulfate is the homogeneous path, involves the hydroxyl radical. The initial rates came, I believe from Castleman's work at Brookhaven.

Let me go back to the EPRI program briefly. Only the SURE program was discussed in the paper, but EPRI does sponsor a number of other studies related to the sulfate problem, including buogenic emissions. They have made, under contract to Doug Davis, the first measurement of the hydroxyl radical in the atmosphere. So we all have programs looking at pollutant transformation processes.



Because of ERDA's past experience with radioactive pollutant transport and removal, they have expertise and interest in both (7) dry deposition and (8) wet deposition and are making the major contribution in the sulfate program to the deposition processes. (9) Weather and climatic effects and (10) numerical modeling. In terms of long-range transport, ERDA has provided the leadership for development of the long-range trajectory models, which will be very useful in this program. In MAP^{3}S, ERDA is interested in the large-scale modeling of the whole northeast area. Some of the modeling results are shown in Dr. MacCracken's paper.

The ERDA program will support a number of aircraft measurements in cooperation with the SURE program. EPRI will do vertical traverses over two class 1 stations. ERDA will fly horizonal paths between several SURE stations during the intensives. Other flight paths will be flown during other times by the ERDA program.

PROGRAMS COORDINATED

It may have been obvious during my talk that these programs are coordinated. We do not feel that any individual program provides a complete answer to the sulfate problem, but all put together, they provide a very good national program on the transport and fate of sulfates. As director of MISTT, I have served as the EPA coordinator. The coordination of this program has been a pleasure, partly because each group has chosen an emphasis which is different from the others and is based on their special interests and capabilities. I hope we will be seeing many more results from this program.

WILLIAM E. WILSON, JR.

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questions & answers

Mr. Joseph A. Consiglio
Solva-Tek Associates

Dr. Arvid Ek
Allegeny County Bureau of Air Pollution Control

Mr. John Hawley
New York State Environmental Conservation

Mr. John Kintz
National Capitol Interstate Planning Committee

Dr. Edward S. Rubin
Carnegie-Mellon University

QUESTION:

On one of the slides, a reference was made to high episodes of 70 to 80 micrograms of sulfate concentrations, and the comment "not attributable or correlatable with local SO_2 concentrations" was made. My question is what does correlate with it, if anything, at this point?

RESPONSE: Dr. William E. Wilson (EPA)

The correlations for the whole year were showing high sulfate in the summer and high SO_2 in the winter. Consequently, there was no correlation. I do not remember what the SO_2 values were during this episode; but as the sulfate built up, the air mass trajectories moved from over general farm country to over river valleys with high SO_2 emissions. In this case, the correlation was with high SO_2 emissions 1 or 2 days upwind of the area. So we would attribute it to transformation during transport.

QUESTION:

Are sulfate emissions related to the trace elements present in the plume? Are you studying that aspect? Different coals have different amounts of trace elements, so the sulfate buildup in the plume downstream should be related to the trace element composition of the coal. Is that being studied also?

RESPONSE: Dr. Wilson

We looked at oil-fired power plumes as distinct from coal-fired power plumes. We found an increase in the initial SO_3 or sulfate in high vanadium oils. There have been suggestions that there is more rapid reaction in the downwind plume; however, this has not been borne out by subsequent studies. As to whether the catalytic metal content will influence reactions in the plume is still an open question. It does influence the initial SO_3 in the stack, but we are not sure of its effect in the downwind plume.

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QUESTION:

There has been much discussion of the possibility of artifact sulfate formation; that is, when high volume filters are used for sulfate eliminations, part of the sulfate is actually produced by perhaps catalytic conversion of sulfur dioxide on the filter surface.

What means do you have of eliminating such artifacts in some of these measurements, both in your studies, Dr. Wilson, and in the SURE studies?

RESPONSE: Dr. Wilson

The filters used in my studies are coarse filters. We have checked for filter conversions by using double filters. We find no sulfate on the second filter. However, if we use Glass Fiber Hi Vol, we find some sulfate on the second filter.

In the EPRI program there will be a special filter, probably teflon-coated glass, which also does not have a surface conversion. This matter of conversion on the filter has been studied quite extensively. For the last few years the glass fiber filters that have been used have generally been neutral rather than basic, and so the sulfate anomaly is very small. So, if we measured 1 or 2 micrograms per cubic meter, we might be concerned, but where we are up 10, 20, or 30 micrograms, it is no longer significant. Using teflon filters and Nucleopore filters in the newer studies, we do not have that problem.

There has also been talk about the possibility of conversion on particles on the filter. This has not been put completely to rest, but apparently is not a major problem.

RESPONSE Dr. Ralph Perhac (EPRI)

Let me add just one thing. We did support a study at Radian Corporation and found that on glass fiber filters for short periods of time, in other words, short air flows, the problem can be serious. Also for low sulfate levels the problem can be serious. However, with long periods of time and high levels, it is not a bad problem. It can also be corrected by pretreating the filter or by, as Dr. Wilson pointed out, use of teflon-coated filters. It is the latter which we will probably use in the SURE program.

RESPONSE: Dr. Wilson

It is true that if we do 1- or 2-hour measurements with high volume filters, we can run into serious problems due to the sulfate conversion on the filter.

QUESTION:

Please clarify your study on regional SO_4 concentrations with an emphasis on local emissions. In what way are you relating this to local emissions?

RESPONSE: Dr. Perhac

We would like to know the effect of changing the local emission of SO_2 on some other region on the ambient sulfate distribution.

RESPONSE: Dr. Wilson

I think Dr. Perhac is correct to say that by local we do not mean the emissions in the immediate vicinity of the sampling station, but the relationship between emissions at any point in the network and regional sulfate.

RESPONSE: Dr. Perhac

Yes. If we put in another 5,000 megawatts in the Ohio Valley, for example, what will be the effect in Pennsylvania or Washington?

QUESTION:

I have a question for Dr. Perhac. In the slide that Dr. Wilson showed, the class one SURE stations are widely dispersed in the eastern United States. Aligning them more in a northeast-southwest fashion, as indicated in phase one of the program, might be the maximum impact orientation because of the alignment of the power plants and the prevailing weather conditions. Why was this done?

RESPONSE: Dr. Perhac

Two reasons. The first one is very simple, money. There just was not enough money to put the stations any closer. We hope to correct that in part by the very extensive network of class two stations which will operate only four times a year. That will separate the class one which will operate every day.

In answer to the second part of your question, why not line them up along the Ohio Valley, that goes back to my comment about wanting random data without a geographic bias. There is no question that by lining them up along the Ohio Valley, we introduce a geographic bias immediately. If there is a trend coming up the Ohio Valley, we will certainly catch it with stations lined up that way; but if there are air flows from other areas, we will miss them. Consequently, we attempted to locate the stations more randomly to eliminate the geographic bias. Admittedly it is a tradeoff, but we felt it was worth it from that standpoint.

QUESTION:

I wonder if one of you gentlemen would discuss the policy implications for those of us who are involved in developing state implementation plans, alert strategies, and so forth. From one of your slides, it seemed that we may not be able to control the air masses that affect us in terms of health and in terms of economics for control strategies. I wondered if someone would discuss the policy implications of the results of your studies to date. Do we in the northeast secede, and say that TVA closed us down?

RESPONSE: Dr. Wilson

Certainly not. The point that I was making essentially involved primary pollutants which have limited lifetimes. We could choose a local region tens of miles or hundreds of miles away and by controlling pollution sources in that area, we would control the area's ambient pollution. When we were concerned with secondary pollutants that have atmospheric lifetimes of days to weeks, our pollution is widely distributed throughout the nation. We are going to have to look on a larger area basis, and we are going to have to think in terms of air quality regions which are much, much larger.

I think the policy people need to be aware of these programmatic results which indicate the long-range movement of pollutants and the type of weather conditions which produce them.

RESPONSE: Dr. Michael C. MacCracken (ERDA)

Let me just add that the intent of the modeling program of ERDA is to look at these large-range policy options. We are trying to focus on options that are well beyond the local scale as opposed to looking at the impact of an individual power plant or several individual power plants.

QUESTION:

The emphasis yesterday morning was based on NO_x. The question is whether any of that is being followed up in terms of modeling studies comparable to what we are seeing for sulfates, particularly for eastern areas?

RESPONSE: Dr. Wilson

I know that all of us are interested in both the gaseous and particulate nitrates. One reason we have not done nitrates is that, until recently, we have not had techniques that were sufficiently sensitive to use in aircraft monitoring for measuring them. We now have a new technique which is sufficiently sensitive for nitrate. At the cooperative study a couple weeks ago, samples were taken on which we will try to do nitrates. We are also looking forward to the next go-around of these field studies in which EPA will have a new acronym called STATE for the study of nitrates as well as organics.

And I might mention that there has been a problem in the past with the formation of sulfate on filters. The formation of nitrate on filters is going to be even worse, but it may be that what we are measuring is gaseous nitrate absorbed on the filter rather than particulate nitrate. It is nitrate that we are measuring, but we are not sure how much is particulate and how much is vapor-based.

So the problem here has not been a lack of interest or concern but a lack of adequate instrumentation.

RESPONSE: Dr. Rudolf F. Pueschel (NOAA)

As far as cloud nuclei formation is concerned, is it necessary for sulfur dioxide to be present? There are other candidates such as nitrogen oxides that could just as well be responsible for this phenomenon.

RESPONSE: Dr. MacCracken

In the SURE program the emissions inventory does include NO_x and also the field measurements will include nitrate measurements, not as extensively as sulfates, but it will include a number of them.

technical discussion

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PROJECT MISTT
MIDWEST INTERSTATE SULFUR TRANSFORMATION AND TRANSPORT

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INTRODUCTION

Sulfate aerosols have been implicated in a variety of adverse ecological and human health effects. The known adverse health effects of sulfur dioxide (SO_2) led to the control of this pollutant (PHS, 1969). However, reductions in urban SO_2 emissions and concentrations, which were produced by the mandatory use of low-sulfur fuels, were not accompanied by a proportional decrease in urban sulfate (EPA, 1975). This observation may be explained by the transformation-transport theory. Reductions in urban SO_2 emissions have been accompanied by increases in rural SO_2 emissions from new power plants located outside cities. Sulfur dioxide from these power plants may be transformed to sulfate in the atmosphere and transported over long distances to urban areas. Interest by the U.S.E.P.A. in the transformation-transport theory led to a major expansion of existing studies by establishing Project MISTT (Midwest Interstate Sulfur Transformation and Transport). The technical approach of Project MISTT is to study the transformations of SO_2 to sulfate in polluted air masses undergoing transport. The intent is to measure pertinent chemical and meteorological parameters with sufficient accuracy so that they may be used with physical and mathematical models to derive rate parameters which characterize the transformation processes. This research should also give insight into transformation mechanisms and serve as a guide for related laboratory studies. Both power plant and urban plumes are being studied.

TECHNICAL DISCUSSION

EPA Plume Studies

Information on the rate of conversion of SO_2 to sulfate in power plant plumes was needed to quantify the contributions of power plants to atmospheric sulfates. A critical review of plume studies (Wilson, 1977) revealed no reliable information on conversion rates, and only two studies provided information on the amount of SO_2 converted to sulfate. To obtain a better understanding of the physical and chemical processes occurring in power plant plumes, extensive studies involving three-dimensional mapping of large plumes were carried out in the St. Louis area as part of the Project MISTT.

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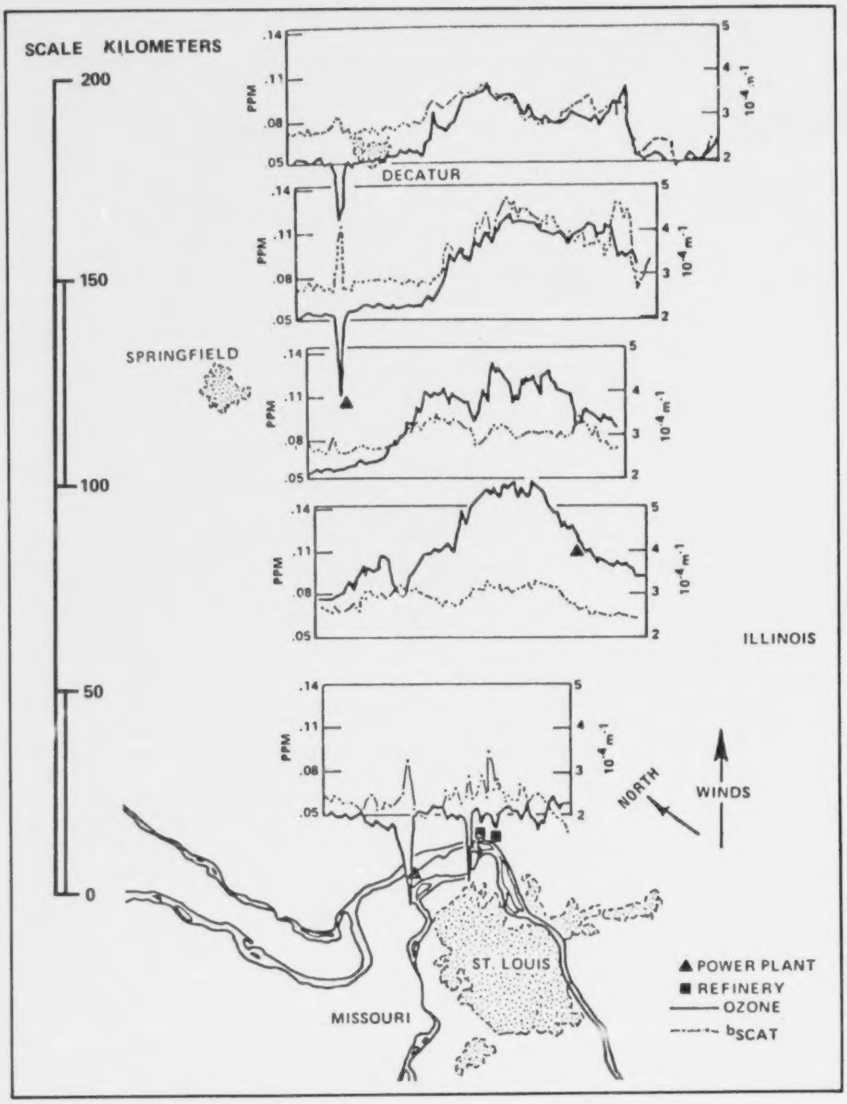
Plume Mapping Program

Two instrumented aircraft, an instrumented van, and three mobile single-theodolite pilot-balloon units were used in a coordinated measurement program. The primary sampling platform was a single-engine aircraft equipped to continuously monitor (1) gaseous pollutants (O_3, NO, NO_x, SO_2) (2) three aerosol parameters (condensation-nuclei count, light-scattering coefficient, and aerosol charge acceptance), (3) several meteorological variables (temperature, relative humidity, dew point, and turbulent dissipation), and (4) navigational parameters. Particulate sulfur samples were collected by a sequential filter-tape sampler equipped with a respirable-particle size separator (Husar et al., 1976a). An optical counter and an electrical-mobility analyzer provided details of the in situ particle-size distribution of grab samples (White et al., 1976a). The flight pattern of the primary aircraft was designed to enable characterization of the plume at discrete distances downwind from the source. At each distance, horizontal traverses were made in the plume perpendicular to the plume axis at three or more elevations. These were supplemented by vertical spirals inside and outside the plume. The instruments continuously monitored the distribution of pollutants along each pass. From the three-dimensional pollutant concentration field obtained in this manner, together with the vertical profiles of wind velocity measured every half-hour by the three pilot balloons units, the horizontal flow rates of pollutants at each downwind distance were directly calculated. From the change in flow rate with distance, it is possible to calculate transformation and removal rates for individual pollutants (Husar, et al, 1976a).

The Urban Plume

The techniques just described were used to map the three-dimensional flow of aerosols and trace gases in power plant plumes and in the air leaving the St. Louis area. It was found that under certain summer, daytime, meteorological conditions, the aggregate pollutant emissions from metropolitan St. Louis often formed a cohesive, well-defined "urban plume" downwind of the city (Husar et al., 1976b; White et al., 1976b). As shown in Figure 1 the 18 July 1975 urban plume was mapped to 180 km northeast of St. Louis. Flow rates within the mixing layer are shown in Figure 2 for O_3, sulfate, and light scattering aerosols. The width of the plume, approximately 40 km, did not change much along the 150-km-distance over which it was obtained. The amount of plume spreading is less than predicted by Gaussian plume models and is probably controlled by the amount of wind shear within the well-mixed layer. It appears likely that the elevated ozone concentrations in this plume and the reduced visibility caused by the plume were exported well beyond 180 km.


SCALE KILOMETERS
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150
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SPRINGFIELD
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3
2
▲ POWER PLANT
■ REFINERY
—— OZONE
-·-·- b_{SCAT}

Figure 1. Ozone concentration and aerosol light-scattering coefficient (b_{scat}) downwind of St. Louis on 18 July 1975. Data are taken from horizontal traverses by instrumented aircraft at altitudes between 460 and 760 m msl. Sampling paths are along graph baselines; note that baseline concentrations are not zero (White et al., 1976b).

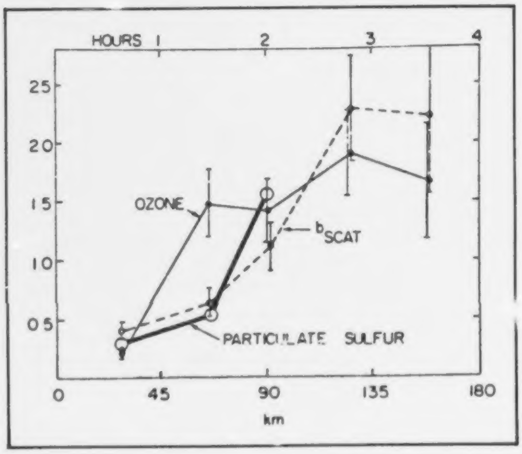

Figure 2. Flow rates and related data for the St. Louis plume on 18 July 1975. Values are plotted against distance downwind of the St. Louis Gateway Arch, with equivalent travel times for a constant mean wind speed of 45 km/hr shown for comparison. The mass flow rate of ozone and particulate and the flow rate of the aerosol light-scattering coefficient (b_{scat}) are shown. Maximum values and units are 2.5 kg/sec for particulate sulfur, 2.5 x 10^2 tons/hr for ozone, and 2.5 x 10^3 b_{scat} units $(10^{-4}m^{-1})(km^3/hr)$.

During a number of experiments in 1974 and 1975, the St. Louis plume was observed to significantly degrade the air quality of communities more than 200 km from the city. The most conspicuous components of the St. Louis plume 50 km or more downwind of the city were the reaction products formed along the way. Unlike the primary pollutants NO and SO_2, ozone and light-scattering aerosols attained their maximum concentrations well downwind of St. Louis and their flow rate increased with distance from the city.

PROGRAM DISCUSSION

Reaction Rates and Mechanisms

In the power plant plumes that have been completely analyzed, the rate of conversion of SO_2 to sulfate varied from 1/2% to 5% per hour. Condensation nuclei counts and aerosol size distribution profiles indicate that the major pathway is a homogeneous reaction, first order in SO_2, and probably involving the OH radical. The reaction rate certainly depends on sunlight intensity (Durham et al., 1977) and appears to also depend on water vapor concentration, background ozone levels, and the extent to which the plume has mixed with background air. The pollutant profiles, in both power plant and urban plumes, resemble those observed in chamber studies and suggest that the current kinetic models can be used to calculate sulfate formation.

Heterogeneous reactions may be important at night, in clouds, or other conditions during which high water vapor content and high relative humidity may lead to the existence of liquid droplets. Attempts to make nighttime measurements during the summer of 1975 were frustrated by difficulties in locating the plume. The use of lidar during the summer of 1976 allowed us to locate the plume but unusually dry conditions led to nighttime relative humidities substantially lower than normal. Therefore, the data analyzed to date do not allow any conclusions regarding heterogeneous reactions. There are, however, several qualitative indications suggesting that under proper conditions heterogeneous reactions may be important and may lead to rates significantly greater than the 5% per hour maximum found for homogeneous reactions. The key parameters governing heterogeneous reactions, in addition to high relative humidities and high water vapor content, are thought to be ozone and ammonia concentrations, concentrations of catalytic species in aerosol form, and the extent of mixing with background air.

Plume Study Techniques

One of the most important advances has been the realization that a plume measurement must be treated as a multi-dimensional problem. In addition to the extent of the plume in the horizontal and vertical direction and the downwind distance, we must consider time as a fourth dimension. We must be concerned not only with the time at which the plume is measured but also the time at which the plume was emitted and the subsequent history of the plume. For example, it may have been a cohesive plume prior to measurement or it may have been highly diluted with background air; it may have been isolated above the mixing layer or it may have been well mixed to the ground; it may have traveled at night, under cloud cover, or in bright sunlight. Much of the early work on plumes has yielded misleading values because the measurements were made only in cohesive plumes early in the morning or late in the evening.

The EPA plume studies differed from earlier ones in that (1) more gas and aerosol parameters were measured, (2) horizontal and vertical profiles were measured, (3) data were interpreted in terms of mass flows instead of concentration ratios, (4) the background air mixing with the plume was characterized, (5) the chemical composition and size distribution of the aerosols in the plume were determined, and (6) measurements were made at the same distance downwind as the plume shape and structure changed with changes in meteorological conditions.

The use of mass flow rate measurements, in addition to SO_2/sulfate ratio measurements, permits a determination of the loss of SO_2 by ground deposition. This technique makes it possible to determine rates during periods when the plume is well mixed to the ground and the SO_2/sulfate ratio measurements alone would yield erroneously high rates. The development of a sulfate analytical technique with sufficient sensitivity for a measurement integrated over one pass through a plume made possible the calculation of sulfate mass flows. On the basis of size distribution profiles, aerosol volume flows were calculated and the results compared. The comparisons gave insight into the type of reaction mechanism.

Transport Distances

The time and distance over which an air mass maintains its integrity depend on its initial size and the meteorological conditions. Power plant and urban plumes have been tracked for 300 km. These plumes maintain their integrity and high pollutant concentrations for much longer times and farther distances than originally expected. During stable nighttime conditions, the cohesive plume is frequently caught in a nocturnal jet which carries it along at as much as twice the normal wind speed. Gaussian plume models are satisfactory for the first few 10's of km, but beyond that wind shear seems to play the dominant role in determining dilution. In urban plumes, wind shear is clearly the determining factor.

Models

Models, of several levels of complexity, have been developed for calculating secondary pollutant concentrations in power plant and urban plumes. These include a multi-step chemical kinetic model and a reacting plume model with relatively simple mixing parameters but with provisions for aerosol formation, coagulation, and growth. In addition, a model has been developed using a sulfate formation rate that is a function of sunlight intensity and that has more sophisticated meteorological terms including multi-layers for vertical diffusion and dry deposition.

Publications and Presentations

Results of Project MISTT have been presented at several national meetings and published in scientific journals. Additional papers will be given at the International Symposium on Sulfates in the Atmosphere to be held in Dubrovnik, Yugoslavia, in September, 1977. The Dubrovnik conference papers will be submitted for publication in Atmospheric Environment. Project MISTT publications and presentations are listed in the Bibliography.

CONCLUSIONS

Power Plant and urban plumes have been sampled out to 300 km from their sources. Sampling at these distances revealed that sulfate, generated from SO_2 in power plant plumes, and ozone, generated from hydrocarbons and nitrogen oxides in urban plumes, may be transported at least hundreds of kilometers and may cause air pollution episodes far from the source of pollution. Air pollution, caused by secondary pollutants, such as sulfates and ozone, cannot be controlled by the government entity where the air pollution impact actually occurs. Therefore, current concepts of air quality control regions must be revised to take into account the long range transport of secondary pollutants.

The present study has concentrated mainly on sulfate, ozone, and light scattering. Plans call for extending the EPA plume studies to include measurements of organic aerosols and vapors, and nitrate aerosols and vapors such as nitric acid. To determine the importance of heterogeneous reactions, more work is needed under conditions of high relative humidity and high water vapor content, which are conducive to heterogeneous reactions. In general, more information is needed to provide better statistics on the parameters than influence reaction rates in power plant and urban plumes.

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26. Whitby, K.T. Physical Properties of Sulfur Aerosols

27. Wilson, W.E. Midwest Interstate Sulfur Transformation and Transport Study (MISTT): Summary.

28. Husar, R.B. Project MISTT - Sulfur Budget in Large Plumes

29. Gallani, N.V. Project MISTT - Plume Model for Dispersion, Transformation, and Removal of SO_2 for 10 Hours of Transport.

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CLOUD NUCLEI GENERATION BY A SULFUR GAS-TO-PARTICLE CONVERSION PROCESS

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INTRODUCTION

It is now recognized that sulfur dioxide (SO_2), as a man-made pollutant, may have effects hundreds of kilometers away from its source, either by acidifying rainfall or, when oxidized to particulate sulfate, by influencing cloud formation and short-wave radiation. According to projections made by the Environmental Protection Agency in its recent Northern Great Plains Resource Program (NGPRP), coal production in the northern Great Plains will rise from 50,000,000 tons in 1975 to over 350,000,000 tons by the year 2000. Part of the fuel development in this area includes utilization of the coal for power generation at mine mouth or at sites providing easy access to the coal supplies. Accordingly, a proportionately larger amount of aerosols and gases will be emitted into the atmosphere. Because of their hygroscopic nature, sulfur aerosols act as centers around which cloud drops form already at relative humidities less than 100%. The measurements reported in this paper reflect the number of cloud droplets that form at 101% relative humidity. This is about the upper limit of humidity encountered in clouds. An increase in the numbers of cloud condensation nuclei (CCN) can lead to a change in the frequency with which clouds form, a different colloidal stability of the clouds, and a difference in the frequency and/or intensity of rainfall.

The economic impact of changes in rainfall can be assessed from the results of previous studies which consider the benefits to be derived from enhancement of precipitation through deliberate weather modification. The change in agricultural production from one inch of incremental rainfall has been estimated at several bushels of grain or several hundred pounds of forage per acre (Special Studies Team, 1973; Johnson, 1972; Bauer, 1972). These figures demonstrate the importance of small changes in amounts of rainfall for agriculture in a semi-arid region. Any such changes in precipitation due to inadvertent effects of energy developments would lead to modification of the High Plains economy, whether such changes are positive or negative.

In the following discussion we show that a climatologically significant aerosol is found among the particulate effluents of a coal-fired powerplant. CCN, efficient at 1.0% supersaturation are formed in the plume at a rate of 10^{15} to 10^{16} per second at distances up to 150 km from the source. By relating the aerosol formation rate to a SO_2 depletion rate due to chemical reaction, a gas (SO_2) to particle ($SO_4^{=}$) conversion process has been isolated as one mechanism by which these nuclei are formed.

TECHNICAL DISCUSSION

The data on cloud nuclei formation that we present here result from investigations that have been conducted since summer 1975 in the plume of the Four Corners Powerplant near Farmington, New Mexico. The plant consists of five pulverized-coal-burning generating units. Two 175 megawatt (Mw) units (ratings nominal) began operating in May and June, 1963. Unit 3, rated at 225 Mw commenced operation in August of 1964. Units 4 and 5, with ratings of 800 Mw were placed in operation in July 1969 and 1970. At full load with all five units in operation, a maximum 25,082 metric tons per day of coal is being used. However, the operating factor is only about 73% and coal consumption is averaging about 18,000 metric tons per day. The coal is classified as sub-bituminous with an average ash content of 22%, and an average sulfur content of 0.7%.

Flue gases from Units 1, 2, and 3 pass through Venturi scrubbers which use cooling lake water to remove particulate matter and sulfur dioxide. The flue gas passes through the scrubber before it is exhausted to the atmosphere at a temperature of about 52°C through chimneys 76.2 m high. Flue gases from units 4 and 5 are passed through electrostatic precipitators before exhausting to the atmosphere at a temperature of approximately 121°C through chimneys 91.4 m high. Figure 1 shows the appearance of the plume downwind to about 8 kilometers. Table 1 gives information on emission rates (Environmental Report, 1975).

The sampling platform for aerosols and gases has been a Cessna 206 instrumented aircraft. Table 2 lists parameters and the recording methods, precision, and accuracy that the aircraft systems package is capable of producing. In this paper only information on CCN and SO_2 concentrations is provided and discussed.

Cloud condensation nuclei are measured with a portable thermal diffussion chamber. It was designed and built in-house by Allee (1970) and is based on the one described by Twomey (1963). The cylindrical chamber consists of two plates, 7.62 cm in diameter and mounted parallel 2.54 cm apart. All walls are lined with blotter paper that is wet during chamber operation. A modest (up to 5°C) temperature difference is maintained between the two parallel wet surfaces. Water vapor is distributed through the chamber by mixing and diffusion. Provided there is no heat loss through the side walls, the water vapor pressure will be related linearly to its temperature. However, since the saturation vapor pressure of water is exponentially related to its temperature, the mixing and diffusion leads to a supersaturated condition. The maximum supersaturation is found roughly mid-way between the surfaces and for small temperature differences is approximately proportional to the square of the

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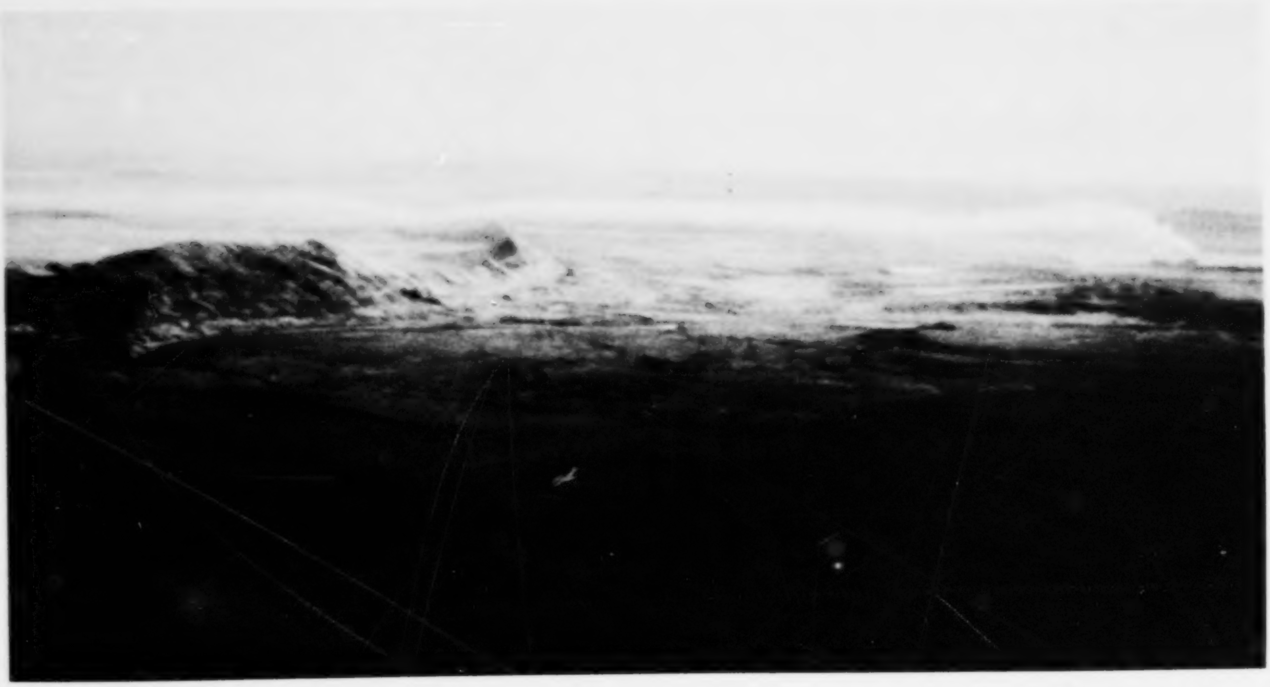

Figure 1. Visual appearance of the Four Corners Powerplant plume. The distance between plant and Hogback Mountains is 4.3 km.

TABLE 1. ESTIMATED CALCULATED PRESENT EMISSIONS AT MAXIMUM RATING

	UNIT NO.				
	1 & 2	3	4	5	Total
SO_2 kg/day ($X10^3$)	39.9	25.4	127	127	319.3
% Removal (Approx)	30	30	0	0	
NO_x kg/day ($X10^3$)	33.5	20.8	69.1	69.1	192.3
% Removal	0	0	0	0	
Particulates kg/day ($X10^3$)	1.9	1.2	38.4	38.4	79.8
% Removal (Approx)	99.2	99.2	97	97	
Net Electrical Output, Mw	350	225	800	800	2175
Energy Input at Full Load (10^6 joules/sec)	1002	621	2066	2066	
Emission Temperature, °C	51.7	51.7	121.1	121.1	
Stack Height, m	76.2	76.2	91.4	91.4	
Stack Diameter, m	5.6	4.6	8.7	8.7	
Exit Volume, m^3/sec (Actual)	536	331	1359	1359	
Exit Velocity, m/sec	21.3	20.1	22.9	22.9	

PARAMETER	UNITS	METHOD OF RECORDING	FREQUENCY OF RECORDING	INSTRUMENT	PRECISION	SENSITIVITY
Cloud Condensation Nuclei	m^{-3}	Photography	Preselected Times	Thermal Diffusion Chamber	± 5%	2×10^{-6}
Aitken Nuclei	m^{-3}	Strip Chart	Continuous	Expansion Chamber	± 10%	1×10^{-4}
Ice Nuclei	m^{-3}	Visual Crystal Counts	Preselected Times	Thermal Diffusion Chamber	± 50%	1.0×10^{-4}
Light Scattering Coefficient	m^{-1}	Strip Chart	Continuous	MRI Integrating Nephelometer	± 5%	$.15 \times 10^{-4}$
Aerosol Size Distribution	m^{-4}	Visual Count Log	Preselected Times	Transmission EM	± 20%	
Aerosol Elemental Composition		Visual Count Log Mag Tape	Preselected Times	Scanning EM X-ray Energy Spectrometry		
Temperature	°C	Strip Chart	Continuous	Thermistor	± 2%	0.25
Relative Humidity	%	Strip Chart	Continuous	Hygrometer	± 3%	0.5
Ozone	ppb	Strip Chart	Continuous	ML Chemiluminescence	± 5%	5.0
Nitrogen Oxide	ppb	Strip Chart	Continuous	ML Chemiluminescence	± 5%	5.0
Sulfur Dioxide	ppb	Strip Chart	Continuous	ML Chemiluminescence	± 10%	10.0

TABLE 2.

PARAMETERS MEASURED BY AIRCRAFT DURING THE FOUR CORNERS POWER PLANT STUDY

temperature difference. The center portion of the chamber is illuminated with a collimated beam of light. After taking in a sample by ram air in the aircraft the chamber is closed, the nucleating drops are given time to grow to visible sizes, and a photograph of the cloud is taken for subsequent counting of the drops after the film has been developed. The number of drops recorded on the film is identical to the number of cloud nuclei in the illuminated chamber volume that are active at the supersaturation that is preselected by the temperature differential between the horizontal walls of the chamber. Figure 2 shows the experimental arrangement of the thermal diffusion chamber.

The analysis for atmospheric sulfur dioxide is accomplished with the Theta Sensors, Inc. polarographic instrument. It utilizes a semipermeable membrane that permits SO_2 to diffuse into the reaction chamber where it undergoes a redox reaction at an electrode. The current generated is proportional to the quantity of gas present. In operation, the lower limit of sensitivity is about 50 ppb (131 μgm^{-3}). Accuracy is ±5% in the range 260 to 1300 μgm^{-3}, and response time is 20 to 25 sec. Interfering gases are H_2S and NO; these produce spurious signals equal to 0.1 and 0.01, respectively, of the response from an equivalent quantity of SO_2.

During the early field operation periods in 1975 and 1976 airborne SO_2 measurements were done with the Meloy Laboratories, Inc. flame photometric sulfur gas analyzer. Measurement of sulfur (S) compounds in the flame photometric detector depends upon the chemiluminescence of S in a hydrogen-rich flame. The intensity of emission when activated S reverts to a lower energy state is directly proportional to a power slightly less than the square of the S concentration. The emission occurs over a broad spectral band with maximum intensity at 394 nm. The intensity of light passing a 394 nm narrow band-pass filter is measured by a photomultiplier tube. The minimum detection level under field operating conditions is about 10 ppb (26 $\mu g\ m^{-3}$) of S in air. Precision and accuracy are approximately 10 ppb. Instrument lag time to 90% of full response is 25 to 30 seconds. The flame photometric detector responds to any gaseous S compound; because SO_2 is the predominant gaseous species under atmospheric conditions encountered in this project, the instrument response is reported as SO_2.

RESULTS AND DISCUSSION

Figure 3 shows the variation in the plume axis of SO_2, the light scattering coefficient (b_{scat}), Ozone (O_3) and CCN as a function of distance L from the stacks. Plotted in Fig. 3 is the ratio of the concentrations measured in the plume axis to the concentrations measured outside of the plume. Typical background concentrations are given in Table 3.

For the subsequent discussion it is to be noted that the decrease with distance of SO_2 in Fig. 3 is opposed to a slight increase of the concentration of CCN. If we fit the data of Fig. 3 to a power curve, we find relationships between constituent ratio C and distance L of the kind $C = C_0 \times L^K$. The case illustrated in Fig. 3 results in values C_0 for SO_2 of 7.58×10^{3}, and for CCN of 1.34. The value of K that determines the change of constituent ratio with distance is -1.42 for SO_2 and 0.18 for CCN. It can be seen that a relativelv strong decrease of SO_2 with

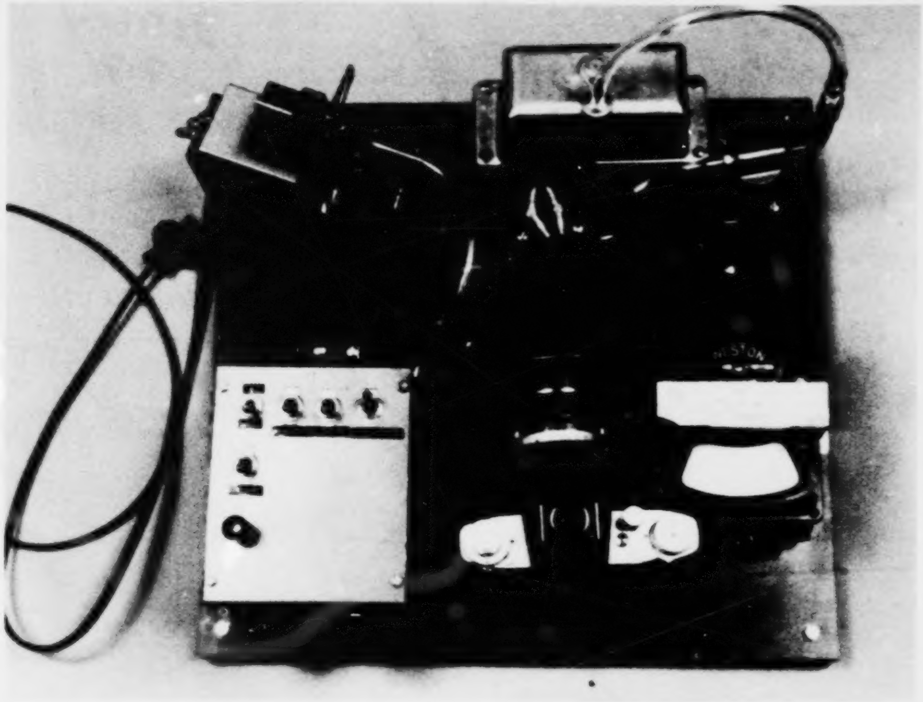

Figure 2. Assembly of the thermal diffusion chamber used in the airborne measurements.

Figure 3. Schematic of the plume model employed in the SO_2 and CCN flux calculations.

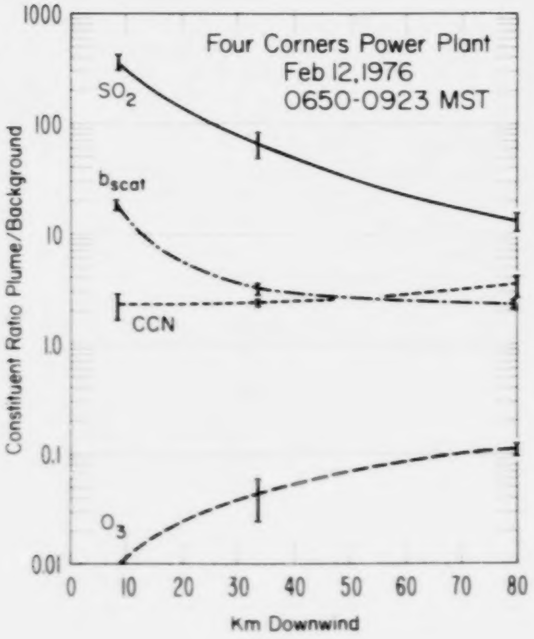

TABLE 3. TYPICAL BACKGROUND CONCENTRATIONS OF ATMOSPHERE PARAMETERS AROUND FARMINGTON, NEW MEXICO

PARAMETER	SYMBOL	CONCENTRATION
Sulfur Dioxide	SO_2	5 - 10 ppb
Ozone	O	25 - 40 ppb
Light Scattering Coefficient	b_{scat}	$1.7 \times 10^{-5} m^{-1}$
Cloud Nuclei Concentration Effective at 1% Supersaturation	CCN	$500 - 1000 cm^{-3}$

distance is opposed by a virtual independence of CCN with distance. Such a result was found during each experiment that was conducted during five measurement periods between July 1975 and October 1976. The values of the parameters C_0 and K for SO_2 and CCN are shown in Table 4 for each experiment.

Figure 4 illustrates the model that we assume for calculation of losses of constituents due to diffusion, deposition, and reaction. The plume is assumed to be emitted at height Z above the ground and travels in the direction L with velocity u. In time $t_1 = L_1/u$, it will pass cross-section 1, and at a later time $t_2 = L_2/u_2$ it will pass cross-section 2. The contribution of diffusion, deposition and reaction to the measured change of SO_2 concentration per unit time, i.e.

$$- \frac{\Delta SO_2}{\Delta t}\bigg|_{MEAS} = \frac{-\Delta SO_2}{\Delta t}\bigg|_{DIF} - \frac{\Delta SO_2}{\Delta t}\bigg|_{DEP} - \frac{\Delta SO_2}{\Delta t}\bigg|_{REAC} \quad (1)$$

can be calculated if the plume dimensions at cross-sections one and two, the wind velocities at times t_1 and t_2, and the vertical and horizontal SO_2 concentration gradients are known. Since all of these parameters are amenable to measurement, the change of SO_2, with time, due to chemical reaction $\Delta SO_2/\Delta t\big|_{REAC}$ can be estimated quite accurately.

In a first approximation and in occasional agreement with observations, we assume that the plume travels in a thin layer downwind to about 8 km from the stacks; at this point it becomes mixed homogeneously in the space between ground and the temperature inversion layer.

Table 5 gives the pertinent plume data for some measurements that were performed in October 1976. The first column in Table 5 shows the date. The second column shows the distances, L, in km at which the measurements were The third and fourth columns, respectively, show the horizontal, H (km), and vertical, Z (m), extents of the plume at distances L. Columns five and six give the vertical, A_V (m^2), and horizontal, A_H (m^2) cross-sectional extents of the plume. Wind speed, temperature and relative humidity are given in columns seven to nine. Table 6 gives the measured mean SO_2 concentration in column three, and the SO_2 flux through the plume cross-sections in column four. The eddy diffusion coefficient, D, given in column five is defined by

$$D = uk\ (z + b) \quad (2)$$

(Junge, 1963) where u is the wind speed at the surface, k is Karman's constant, Z is altitude and b is the roughness parameter of the surface. The settling velocity, v_G of SO_2 molecules to the ground in column six is calculated as

$$v_G = D\ (m_{SO_2} - m_{air})\ \frac{g}{kt} \quad (3)$$

TABLE 4. POWER CURVE FIT $C_L = Co \times L^K$ BETWEEN CONSTITUENT C MEASURED IN THE PLUME AXIS AT DISTANCE L FROM THE STACKS AND L. r^2 IS THE COEFFICIENT OF DETERMINATION

DATE	SO_2			CCN		
	Co (ppm)	K	r^2	Co (cm^{-3})	K	r^2
7-29-75			1.0	1461*	-0.07	0.04
7-30-75				3745*	-0.35	0.92
8-01-75				4475*	-0.16	1.00
10-14-75				3358*	-0.01	1.00
10-16-75	36.61	-1.43	0.92	5228*	-0.02	0.78
10-17-75	40.94	-1.53	0.96	8077*	-0.18	0.89
2-11-76	26.05	-1.13	1.00	8078**	-0.09	0.50
2-11-76	50.57	-1.49	0.99	6288**	-0.02	
2-12-76	23.35	-0.98	0.88	1740	+0.23	0.31
2-13-76	8.11	-1.13	0.96	20631**	-0.38	0.81
6-25-76	63.5	-1.75	0.94	237	+0.45	0.93
6-26-76	6.72	-1.14	1.00	824	+0.03	0.01
6-27-76	19.0	-1.46	1.00	638	+0.28	1.00
10-8-76	- 2.26*	-1.50	1.0	2187*	-0.07	0.28
10-9-76	24.99*	-1.39	0.96	8546*	-0.48	0.54
10-10-76	9.31*	-1.14	1.0	5009*	-0.28	1.00
10-11-76	45.10*	-1.59	1.0	7212*	-0.28	1.00

*RH < 20%

**RH > 50%

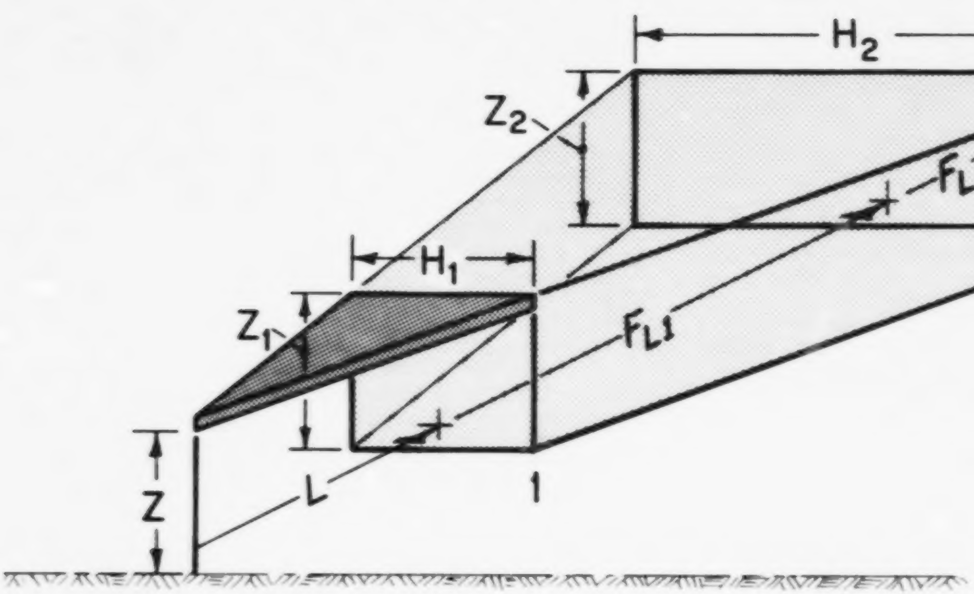

Figure 4. Variations with distance L from the stacks of SO_2, b_{scat}, CCN and O_3

TABLE 5. RELEVANT PLUME PARAMETERS

DATE	L (km)	H (km)	Z (m)	A_V (m^2)	A_H (m^2)	u (m sec^{-1})	T (°C)	RH (%)
10-8-76	8	12	163	1.96×10^6	4.80×10^7	1.7	7.8	20
	32	17.8	163	2.90×10^6	2.84×10^8	1.7	5.6	17
10-9-76	8	3.1	240	7.44×10^5	1.24×10^7	1.5	12.2	12
	80	28.4	152	4.32×10^6	1.14×10^9	1.5	12.2	10
10-10-76	8	11.6	229	2.65×10^6	4.64×10^7	2.3		
	32	20.0	193	3.86×10^6	3.20×10^8	2.5	14.4	12
	80	26.7	200	5.34×10^6	1.07×10^9	3.2	14.4	12
10-11-76	8	2.7	224	6.04×10^5	1.08×10^7	7.0	12.2	10
	32	9.8	183	1.79×10^6	1.56×10^8	6.0	16.7	8

TABLE 6. SULFUR DIOXIDE FLUXES AND RATES OF CONVERSION

DATE	L (km)	SO_2 ($\mu g\ m^{-3}$)	F_L ($\mu g\ sec^{-1}$)	D ($m^2\ sec^{-1}$)	v_G ($m\ sec^{-1}$)	F_G ($\mu g\ sec^{-1}$)	$\frac{\Delta SO_2/REAC\ (hr^{-1})}{\Delta t}$
10-8-76	8	2.1×10^3	7.0×10^9	1.11×10^2	1.52×10^{-2}	1.53×10^9	5.46×10^{-2}
	32	5.24×10^2	2.58×10^9	1.11×10^2	1.52×10^{-2}	1.87×10^9	
10-9-76	8	4.19×10^3	4.68×10^9	1.44×10^2	1.97×10^{-2}	1.03×10^9	8.24×10^{-3}
	80	1.38×10^2	8.49×10^8	1.44×10^2	1.97×10^{-2}	3.06×10^9	
10-10-76	8	2.20×10^3	1.63×10^{10}	2.56×10^2	3.51×10^{-2}	3.58×10^9	1.91×10^{-2}
	32	7.58×10^2	7.58×10^9	1.93×10^2	2.64×10^{-2}	6.64×10^9	1.77×10^{-2}
	80	1.05×10^2	1.79×10^9	2.56×10^2	3.51×10^{-2}	3.94×10^9	
10-11-76	8	3.67×10^3	1.55×10^{10}	7.02×10^2	9.62×10^{-2}	4.35×10^9	2.08×10^{-2}
	32	7.86×10^2	8.44×10^9	4.39×10^2	6.01×10^{-2}	4.91×10^8	

where m_{SO_2} is the mass of the SO_2 molecule, m_{air} is the mass of air molecules, g is acceleration due to gravity, k is Boltzmann's constant, and T is temperature. The vertical flux, F_G in column seven, follows as

$$F_G = V_G \times (SO_2) \times A_H \qquad (4)$$

where V_G is settling velocity, (SO_2) is SO_2 concentration and A_H is horizontal plume area. The net change of SO_2 concentration due to chemical reaction is

$$SO_2\Big|_{REAC} = F_{L_1} - F_{L_2} - F_G, \qquad (5)$$

i.e., the differences of SO_2 fluxes through the plume cross-sections at L_1, L_2 and the ground. The relative SO_2 uptake by chemical reaction per hour is shown in column eight.

The rate of change of CCN with time is

$$\frac{\Delta CCN}{\Delta t}\Big|_{MEAS} = \frac{\Delta CCN}{\Delta t}\Big|_{COAG} - \frac{\Delta CCN}{\Delta t}\Big|_{DIF} - \frac{\Delta CCN}{\Delta t}\Big|_{DEP} + \frac{\Delta CCN}{\Delta t}\Big|_{REAC}. \qquad (6)$$

The diffusion and deposition terms are negative, that is, they represent losses of fine particles, whereas the positive coagulation and reaction terms indicate the formation of CCN. The diffusion and deposition losses for CCN can be calculated similarly to those for SO_2 with the proper settling velocity in Equ. 3 (Fuchs, 1964).

Table 7 summarizes the results of the CCN measurements. The dates in column one correspond to the dates in Tables 5 and 6. Column 2 lists the distances from the stacks at which the experiments were performed. Column 3 shows the cloud nuclei concentration per cubic meter. Column 4 gives the flux through vertical plume cross-sections at distances L. Column 5 gives the flux of cloud nuclei to the ground as calculated by Equ. 3 with a settling velocity $v_G = 2.2 \times 10^{-6}$ m sec^{-1} corresponding to sulfuric acid (H_2SO_4) droplets of size $r = 10^{-6}$ cm. The net increase of CCN per unit time in column 6 is the flux out of the box of Figure 2, minus the flux going into the box, i.e.,

$$\frac{\Delta CCN}{\Delta t} = F_{L_2} + F_C - F_{L_1} \qquad (7)$$

The size range of cloud nuclei that are of interest in this discussion is $10^{-6} cm < r < 10^{-5} cm$, where r is the particle radius. The upper size limit follows from simultaneous nephelometer measurements that verified the inability of the freshly formed nuclei to scatter visible light (see Fig. 3). The lower size limit is based on observations by Junge and McClaren (1971) who have shown that the critical radius of a water soluble cloud nucleus must be at least $r = 10^{-6}$cm in order to grow unstably at 1% supersaturation.

Suppose that all the nuclei that are formed are made up of H_2SO_4. This would correspond to a formation mechanism

$$\begin{aligned} 2SO_2 + O_2 &\rightarrow 2SO_3 \\ SO_3 + H_2O &\rightarrow H_2SO_4. \end{aligned} \qquad (8)$$

If, on the average (see Table 6), 2% per hour of 700μg m^{-3} of SO_2 are converted to H_2SO_4 at L_2=32km, then 14μg m^{-3} $hour^{-1}$ of SO_2 are used up to form 21.4μg $m^{-3}hour^{-1}$ of H_2SO_4. With an average plume volume of 6×10^{12} m^3 at L_2 = 32km, the formation rate of H_2SO_4 is 3.6×10^2g sec^{-1}. This corresponds to a formation rate of 10^{16} sec^{-1} of CCN of size $r = 10^{-5}$cm, which is in good agreement with the experiment.

The simple model (Fig. 4) on which the rate calculations are based probably overemphasizes the

DATE	L (km)	CCN (m^{-3})	$F_L \left(\frac{CCN}{sec}\right)$	$F_G \left(\frac{CCN}{sec}\right)$	$\frac{\Delta CCN}{\Delta t}$ (sec^{-1})
10-8-76	8	2.0×10^9	6.7×10^{15}		
	32	2.0×10^9	9.9×10^{15}	1.0×10^{12}	3.2×10^{15}
10-9-76	8	4.0×10^9	4.5×10^{15}		
	80	1.5×10^9	9.7×10^{15}	3.7×10^{12}	5.2×10^{15}
10-10-76	8	2.0×10^9	1.5×10^{16}		
	32	1.9×10^9	1.9×10^{16}	1.1×10^{12}	4.0×10^{15}
10-11-76	8	4.0×10^9	1.7×10^{16}		
	32	2.7×10^9	2.9×10^{16}	8.8×10^{11}	1.2×10^{16}

TABLE 7. CLOUD CONDENSATION NUCLEI FLUXES AND RATES OF FORMATION

deposition fluxes, since in reality a smaller portion of the plume has contact with the ground than has been assumed in the model. This is compensated for in part by the assumption that the lower SO_2 concentration at distance L_2 prevails over the overall distance $L_1<L<L_2$. In the case of CCN, it is partly compensated for by basing the flux calculation to the ground on the settling velocity for $r = 10^{-6}$cm sized particles.

The low rate of about 1% per hour of SO_2 that is converted to sulfates is compatible with the low ozone concentration that has been measured (see Figure 3), and with the probable absence of other oxidizing species. Furthermore, it supports the notion that a mechanism as shown in Equ. 8 is responsible for H_2SO_4 formation. Note that in Table 5 the higher conversion rate was observed when the humidity approached 20%. In this connection it is also to be noted that the highest formation rate of CCN was found during the February 13, 1976 experiment (Table 4) when the relative humidity exceeded 50%. This lends support to an accelerated liquid phase oxidation mechanism of SO_2 (Scott & Hobbs, 1967).

The source strength listed in Table 7 for CCN from a coal-fired powerplant is significantly less than the global anthropogenic source strength of 10^{20} to 10^{21} sec^{-1}. It is comparable, however, with the strengths of other industrial activities and medium-sized industrial-urban complexes, (Radke and Hobbs, 1976). Comparing the source strength for CCN of a coal-fired powerplant with the production rate of natural CCN for land of 5×10^6 m^{-2} sec^{-1} (Squires, 1966) and realizing that the SO_2 conversion time is on the order of hours to days, and the residence times of fine particles in the atmosphere is on the order of days to weeks, it becomes apparent that the atmospheric CCN budget in the regional or even short mesoscale surrounding power generating stations is dominated by the nuclei from this single anthropogenic source. In view of the effects that CCN can have on cloud structure and precipitation processes, immediate attention should be given to possible changes in the microstructure of clouds in the northern Great Plains downwind from powerplants.

SUMMARY AND CONCLUSIONS

Measurements of SO_2 gradients in the plume of the Four Corners coal-fired powerplant led to an estimate of SO_2 conversion rates on the order of a few % per hour. This value is compatible with an observed formation rate of 10^{15} to 10^{16} sec^{-1} of CCN under the assumption that they are initially composed of H_2SO_4.

The source strength for CCNs of coal-fired powerplants is of similiar magnitude to the strengths of large Kraft pulp mills, aluminum smelters, and intermediate urban-industrial areas.

Most important for climatic implication is the fact that the rate of formation of CCN from one isolated powerplant is as large as is the formation rate of land surfaces of comparable extent. This doubling of the total atmospheric CCN concentration indicates that the inadvertent modification of clouds and precipitation downwind from the plants is possible in the regional scale, perhaps even in the mesoscale. Both the amount and frequency of rainfall, and the acidity of precipitation can be affected.

The gas-to-particle conversion process as a mechanism by which cloud nuclei are formed acts in addition to the one discussed elsewhere (Pueschel, 1976), where it was established that the condensation on silicaceous flyash particles of water-soluble sulfates renders these particles efficient in the condensation of water at supersaturations less than 1%. The gas-to-particle formation process is probably the more important one because of the slow conversion rate of SO_2 in the absence of excessive moisture and without high oxidant concentrations. This process also takes place in those cases where the particulate removal is more efficient, resulting in a larger amount of gaseous sulfur to be emitted to the atmosphere. It has been suggested (Pueschel, 1976) that preferential adsorption of sulfur gas into large, easily collected particles of a heat-stable molecular sieve entrained with the feed air may offer a solution to the excessive emission of SO_2 to the atmosphere during coal combustion.

ACKNOWLEDGMENTS

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TRANSPORT AND TRANSFORMATION OF SULFUR OXIDES IN THE TENNESSEE VALLEY REGION

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INTRODUCTION

The Tennessee Valley Authority (TVA) is studying the transport and transformation of pollutants from coal-fired power plants in the Tennessee Valley region. Existing meteorological and aerometric networks afford a unique opportunity to obtain detailed information on these processes with a minimum of additional expense.

Two kinds of pollutants may result from any emission source. Primary pollutants are emitted through stacks directly into the atmosphere. Once entrained into a moving airmass, the primary pollutants may react with other components of the airmass, typically by oxidation processes, to produce secondary pollutants. Many of the higher oxides are reported to be more toxic than their precursors. Because secondary pollutants are formed during transport, there is concern that their impact may be experienced hundreds or thousands of kilometers downwind from the source.

Although data are being collected on nitrogen oxides, hydrocarbons, and ozone, research is emphasizing gaseous and aerosol sulfur oxides.

An understanding of (1) the mechanism by which secondary pollutants are formed in the atmosphere and of (2) the influence of meteorological and plant operating variables on the rate at which they are formed is essential to the most effective application of control technology.

TECHNICAL DISCUSSION

TVA is using two regimes of time and distance in its studies. In the first regime, rates of conversion of primary pollutants to secondary pollutants are measured within the plume of a single power plant that is isolated from other significant sources of air pollutants. These measurements generally correspond to reaction times in the atmosphere of a few hours or less and usually are made within 100 km of the power plant. The second regime uses a large section of the TVA system, encompassing several large power plants, as an area source for mass balance measurements for a box-shaped model region measuring several hundred kilometers on each side. These studies indicate the pollutant loading imposed by the system as a whole on an airmass that traverses the region.

Instrumented aircraft have been used to determine the rate of sulfate ($SO_4^=$) production in the plume of a 2600-MW coal-fired power plant. Measurements made 10 to 105 km downwind during the fall and winter months showed that 1 to 2 percent of the sulfur in the plume is in the form of sulfate aerosol. The measurements indicated no increase in the percentage of sulfate aerosol in the airmass as it moves away from the power plant (**Figure** 1). However, the fraction of sulfur in the form of sulfate aerosol in samples taken from the plume was larger than that in samples collected at the base of the stack. This would indicate that a small amount (about 1 percent) of the sulfur dioxide (SO_2) is converted to $SO_4^=$ in the immediate vicinity of the power plant after which the conversion rate is immeasurably slow (less than 2 percent per hour).

X-ray fluorescence analyses have been performed on individual particles collected within the plume. The lack of correlation found between the amount of sulfur in these particles and distance traveled supports the results described above. However, a strong correlation has been found between particle size and sulfur content; particles less than 1 μm in diameter contain much more sulfur than the larger particles. These small particles can be transported long distances and can penetrate deep into the human respiratory tract.

Nitric oxide (NO) is converted to nitrogen dioxide (NO_2) much more rapidly than SO_2 is converted to $SO_4^=$. Typically, 50 percent of the NO has reacted by the time it has moved 30 km downwind from the plant. Near the plant, ambient ozone is almost totally consumed within the plume boundaries. Ozone is almost certainly responsible for the oxidation, because the amount of ozone removed approximately equals the amount of NO converted to NO_2. Davis found that ozone concentrations increase downwind from a power plant (1). However, a series of ozone profiles for two coal-fired power plants in the TVA system during summer, fall, and winter months evidenced no excess ozone. Therefore, ozone production should be considered a phenomenon that exists only for a specific set of circumstances.

A photochemical reaction chamber is being constructed for detailed studies of the mechanisms of plume transformation. The conversion that occurs in synthetic gas mixtures and in stack gases from an operating power plant will be studied under controlled conditions in this chamber. Experiments are expected to begin in the fall of 1977.

An 800- by 500-km rectangular area in the Tennessee Valley (**Figure** 2) was chosen for studying the regional transport of emissions. A smaller area (shown with dashed lines in **Figure** 2), 300 km on a side, was selected for a field study during February and March of 1976. About 50 percent of all SO_2 emissions within the Tennessee Valley region originate in this area, and it contains one of the most complete aerometric and meteorological networks in the country--13

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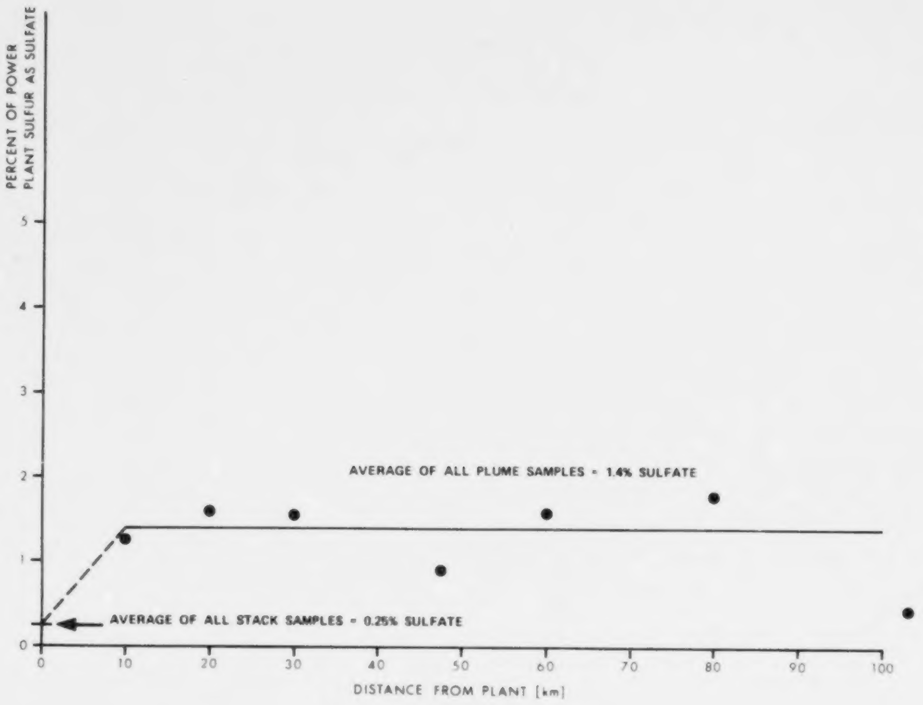


Figure 1.

Percentage of airborne sulfur as sulfate aerosol at various distances downwind from a 2600-MW coal-fired power plant. Data collected on eight sampling days were averaged for various distances downwind.

aerometric stations and 20 meteorological sites. The ground-level monitoring system was supplemented with sampling from an airplane.

Total gaseous sulfur, hydrocarbons, and ozone were measured continuously, and particulates were collected on filters for measurements of $SO_4^=$ concentrations. Temperature, dew point, and altitude were also recorded. The experiment was restricted to days on which the winds were from the south or southwest sector, which is the general direction of prevailing winds during February and March. Filters exposed at eight ground-level sampling sites were analyzed for nitrates, ammonium, SO_4, and total suspended particulates. The TVA Meteorological Forecast Center at Muscle Shoals provided forecasts of air parcel trajectories, data concerning upper air wind, and other information as needed.

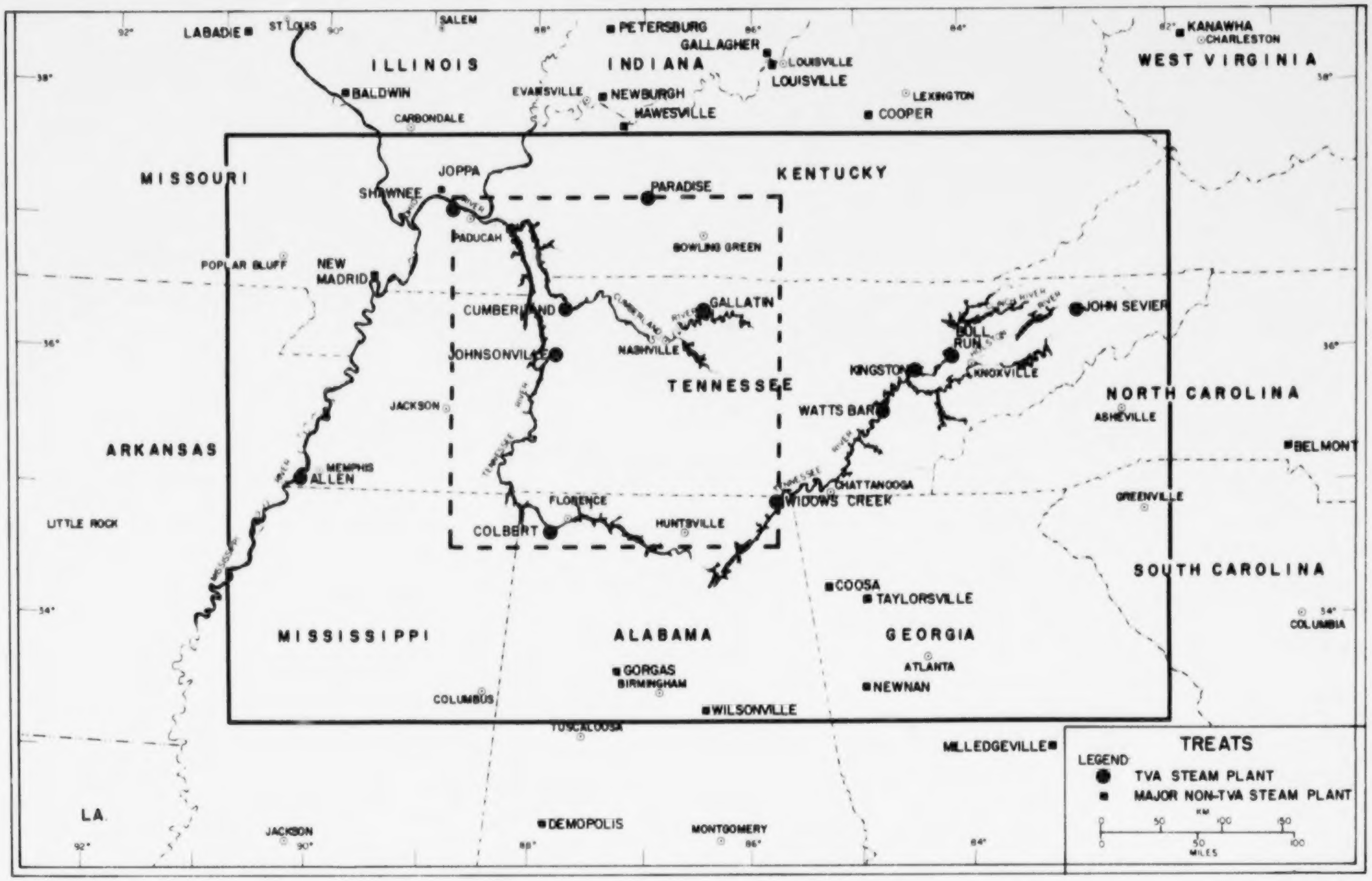
Preliminary results indicate that, on days when Lagrangian measurements of air parcels were made, the average $SO_4^=$ flux into the area was 31 $\mu g\ m^{-2}\ sec^{-1}$ and out of the area was 47 $\mu g\ m^{-2}\ sec^{-1}$. Comparison of data from filters from high-volume samplers at ground level near the entry and exit boundaries of the study area indicate a 25-percent increase in SO_4 concentrations and a 36-percent increase in total suspended particulate concentrations. Additional studies planned for the summer of 1977 must be completed before generalized conclusions can be drawn from these results.

To describe diurnal inversion conditions, measurements were made on four mornings within and above radiation inversions. The results indicated average SO_4 concentrations of 3.9 $\mu g/m^3$ within the inversion and 1.2 $\mu g/m^3$ above it. Concentrations within the inversion differed from those above it by a factor of at least two in all four cases.

PROGRAM DISCUSSION

The ambient levels of primary and secondary pollutants downwind from a single coal-fired power plant or a system of such plants depend on the relative importance of transport, conversion, and removal processes competing for these species. Any method for predicting these concentrations will require that these processes be quantified. The measurements described in this study will be used for this purpose. The effects of wider variety of meteorological and plant operation conditions need to be investigated before general conclusions can be made. Studies are planned to investigate the effects of photochemical processes, temperature and relative humidity, and mass loading: (1) Day and night flights will be conducted during the summer to investigate the contribution of photochemical processes to the conversion rate; (2) winter and summer data will be compared to test for correlations with temperature and relative humidity; and (3) electrostatic precipitators will be operated at various efficiencies to determine the effect of particle concentrations on the production of $SO_4^=$.

The field study conducted in 1976 provided valuable insight into the scope of the problem of regional transport of emissions from coal-fired power plants. It is believed to have been the first measurement program in which Lagrangian and Eulerian measurements of airmasses were made for a


TREATS
LEGEND
TVA STEAM PLANT
MAJOR NON-TVA STEAM PLANT
KM
MILES
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INDIANA
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WEST VIRGINIA
MISSOURI
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
ARKANSAS
MISSISSIPPI
ALABAMA
GEORGIA
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ST LOUIS
SALEM
PETERSBURG
GALLAGHER
LOUISVILLE
KANAWHA
CHARLESTON
BALDWIN
EVANSVILLE
NEWBURGH
HAWESVILLE
LEXINGTON
COOPER
CARBONDALE
JOPPA
SHAWNEE
PADUCAH
PARADISE
BOWLING GREEN
POPLAR BLUFF
NEW MADRID
CUMBERLAND
GALLATIN
NASHVILLE
JOHNSONVILLE
JOHN SEVIER
BULL RUN
KINGSTON
KNOXVILLE
WATTS BAR
JACKSON
ASHEVILLE
BELMONT
MEMPHIS
ALLEN
CHATTANOOGA
WIDOWS CREEK
FLORENCE
GREENVILLE
LITTLE ROCK
COLBERT
HUNTSVILLE
COOSA
TAYLORSVILLE
COLUMBIA
GORGAS
BIRMINGHAM
ATLANTA
NEWNAN
COLUMBUS
WILSONVILLE
TUSCALOOSA
MILLEDGEVILLE
DEMOPOLIS
MONTGOMERY

Figure 2. Tennessee Regional Atmosphere Transport Study area. The solid rectangle (800 x 500 km) is the area for which a regional model is being developed, and the dotted square (300 x 300 km) shows the area in which the 1976 spring field study was conducted.

study of the transport of SO_2 and $SO_4^=$ over an area measuring several hundred kilometers on each side.

The formation and transport of $SO_4^=$ could possibly be measured more accurately if measurements were made simultaneously at the entry and exit boundaries of the study area. Use of two aircraft would permit sampling of the same airmass as it entered the Valley and as it left. Comparison of such measurements would yield better estimates of the contribution of Tennessee Valley sources to the SO_2-$SO_4^=$ complex.

CONCLUSIONS

Although more experiments and data are required before the questions that initiated this research can be fully answered, a few general conclusions are suggested by the results obtained to date:

1. Under fall and winter conditions--fairly low temperatures and low moisture content--the oxidation of SO_2 to $SO_4^=$ appears to be very slow except in the immediate vicinity of the power plant.

2. The conversion of NO to NO_2 is fairly rapid and presumably occurs by reaction of NO with ambient ozone.

3. Under none of the conditions investigated was any evidence found of a net production of ozone in the plumes of coal-fired power plants.

4. Ground-level measurements near the entry and exit boundaries of the study area indicate that $SO_4^=$ concentrations increase 25 percent and total suspended particulate concentrations increase 36 percent.

5. Measurements made from aircraft indicate that the $SO_4^=$ flux in airmasses leaving the study area is 16 $\mu g\ m^{-2}\ sec^{-1}$ greater than that in airmasses entering the study area.

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SULFATE REGIONAL EXPERIMENT OF ELECTRIC POWER RESEARCH INSTITUTE

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INTRODUCTION

The Sulfate Regional Experiment (SURE) comprises an extensive program of measuring atmospheric pollutants throughout the northeastern United States. This $5-1/2-million project, funded by the Electric Power Research Institute (EPRI), is aimed primarily at defining the regional, ambient concentrations of secondary pollutants (e.g., sulfates) in terms of local emissions of primary precursors (e.g., SO_2). Emphasis, of course, is on sulfates; however, other pollutants will also be measured. Of particular concern is the contribution of the electric power industry to regional sulfate levels. The basic elements of SURE are: (1) a ground- and air-based measurement program; (2) an emissions inventory; and (3) development of a model to predict regional concentrations as a function of local emissions.

EPRI's concern with sulfur pollution arises from the anticipated tremendous increase in coal burning during the next few decades. Almost certainly, an increased use of coal will be a major means of satisfying the nation's energy needs. And even with extensive use of low-sulfur coals from the West, a marked increase in sulfur loading of the atmosphere can be expected. A number of inhalation toxicology studies have already shown that sulfur aerosols produce respiratory difficulties. And EPA has implicated sulfates as potential health hazards. The extent to which sulfur-species aerosols affect man and the exact nature (chemical speciation) of such aerosols is far from known; nevertheless, concern is sufficiently widespread so that EPRI has as a major program the physical chemistry of sulfur in the atmosphere, as well as the health effects of sulfur compounds.

A major concern of the electric power industry centers on the possibility that an ambient sulfate standard may be promulgated. The impact of such a standard on the power industry would be severe. The Sierra Club has already brought suit against EPA to impose such a standard - probably at a level of ±10 ug/m^3. Most sulfate is formed in the atmosphere by chemical conversion from a precursor (SO_2). The amount of sulfate produced by direct combustion is small - probably not more than a few percent of the total emitted sulfur. For this reason, the only way to meet an ambient sulfate standard seems to be by control of SO_2 emissions. Unfortunately, we have no evidence to suggest that any sort of direct relation exists between emitted SO_2 and ambient sulfate, hence reducing SO_2 by some factor may really have little bearing on sulfate levels. Some evidence suggests quite the contrary (Altshuller, 1976). In a number of cities, for example, SO_2 emissions have been reduced considerably over the past few years, yet sulfate levels have remained nearly constant. And throughout much of the Northeast, sulfate levels reach maxima in summer whereas SO_2 emissions are highest in winter. Of course, eliminating all SO_2 would almost certainly reduce sulfate levels but total elimination of SO_2 emissions is drastic and unattainable. With our present knowledge, we have no way of knowing how much to reduce SO_2 emissions in order to effect a specific reduction in ambient sulfate concentrations. And we will not know until a firm relation between emissions and ambient concentrations is established - hence SURE.

BACKGROUND

A number of studies, among them those of Lioy et al. (1976), certainly suggest that the sulfate problem (i.e. formation of sulfates in the atmosphere) is a regional one which may be intimately related to atmospheric transport phenomena and chemical reactions occurring over distances of hundreds of kilometers. Evidence for the regional nature of the problem comes from a number of sources. What few kinetic data are available (EPA, 1976; Halstead et al, 1977) suggest transformation rates (SO_2 to sulfate) of 1 or 2 percent/hour, hence considerable distances would be involved in generating significant quantities of sulfates. Analysis of the abundant data from the U.S. National Air Surveillance Network also supports the idea that great distances are involved in sulfate formation. Evidence is also drawn from the regional extent of visibility reduction and the occurrence of acid rain, both of which phenomena may be related, in part, to atmospheric sulfate particles (Galloway et al., 1976; Cass, 1976).

Within the United States, the highest sulfate levels occur in the Northeast (Hakkarinen and Hidy, 1976). Concentrations ranging from 5-25 ug/m^3 are typical. (During "episodes" values up to 80 ug/m^3 have been recorded.) This is in marked contrast to the 3-4 ug/m^3 commonly measured in the West. Because of the high Northeast values, EPRI, decided to initiate a regional sulfate study - focusing the effort on the populous Northeast.

Before embarking on a major project, EPRI first supported a 1-year planning study at a cost of about $250,000 (EPRI, 1976). The goal of the study (which was carried out by Environmental Research and Technology - ERT) was to evaluate if, in fact, the sulfate problem is regional and what sort of measurement program might resolve the issue. The study involved mainly the use of existing data - meteorological, emissions, and SO_2 concentrations. In addition, over 3000 existing filters (which had been stored) from northeastern monitoring stations were analyzed for sulfate content.

The planning study yielded four principal findings relative to the Northeast:

1. Sulfate levels differ more widely (in space and time) than do those for SO_2.

2. The summer sulfate highs do not co-relate with SO_2 highs which occur in winter.

3. High sulfate concentrations seem to correlate with both temperature and dew point and with high pressure air masses (maritime tropical airflows).
4. High sulfate concentrations are not correlative with local SO_2 emissions or with continental polar air masses.

These findings do suggest that an extensive regional study aimed at measuring both chemical and meteorological parameters is a means of resolving the Northeast sulfate questions. Again, the real question is: what is the electrical power industry's contribution to ambient sulfate levels?

THE SURE PROGRAM

SURE comprises four distinct, yet interwoven elements: an extensive ground-level measurement program, a more limited aircraft program; a detailed emissions inventory, and a modeling effort. The program, which is currently funded at a total level of $5.5 million, began late in 1976 and will be completed early in 1980.

Ground Network

The heart of SURE is a network of 54 ground stations distributed somewhat randomly (geographically) throughout the northeastern United States (Figure 1). Nine of the stations are designated as Class I stations, the remaining 44 as Class II. These classes of stations differ both in the type of measurements made and in the frequency of sampling. (See Appendix A for details of and quality control for the parameters to be measured.) In general, the Class I stations will operate every day for a period of 19 months. The parameters to be measured are listed in Appendix A. The specific Class I sites were selected so as to be representative of rural concentrations and to be uninfluenced by a single major source. The Class II stations will operate only four months out of each year; the four months corresponding to the middle months of each season: January, April, July, October. During these so-called intensive periods, the Class II stations will gather data daily (Appendix A). Inasmuch as the SURE program will operate for 19 months, the Class II stations will function during six intensives. The Class II stations were selected in such a way as to give random representation and also to take advantage of existing monitoring sites. An attempt was also made to use sites which are not influenced unduly ay a single source, but not every station necessarily meets this last qualification.

SURE Class I Stations

100A	Montague, MA	107	Giles City, TN
102	Scranton, PA	109	Chapel Hill, NC
103A	Indian River, DE	111A	Roanoke, IN
104B	Philo, OH	112	Lewisburg, WV
106	Rockport, IN		

SURE Class II Stations

1	E. Beverly, MA	24	Loves Mill, VA
2	Fall River, MA	25	Hytop, AL
3	Albany, NY	26	Giles City, TN
4	Oswego, NY	27	Paradise, KY
5	Dunkirk, NY	28	Memphis, TN
6	Roseton, NY	29	Hanover, NH
7	Allegheny, PA	30	Benton Harbor, MI
8	Lewisville, PA	31	St. Louis, MO
9	Brush Valley, PA	33	Niles, OH
10	Gettysburg, PA	35	Madison, WI
11	Delmarva, DE	36	Galesburg, IL
12	Gavin, OH	37	Mount Storm, WV
13	Clifty Creek, IN	38	Chesterfield, VA
14	Big Sandy, OH	39	Yorktown, VA
15	Breed, IN	40	Riverbend, NC
16	Munroe, MI	41	Weatherspoon, NC
17	Port Huron, MI	42	Atlanta, GA
18	Kincaid, IL	43	(Upstate New York)
19	Collins, IL	46	Columbia, SC
20	Picway, OH	47	Cayuga, NY
21	Jay, ME	48	Dan River, NC (?)
22	Toronto, Ont	49	Lafayette, IN
23	Huntington, NY		

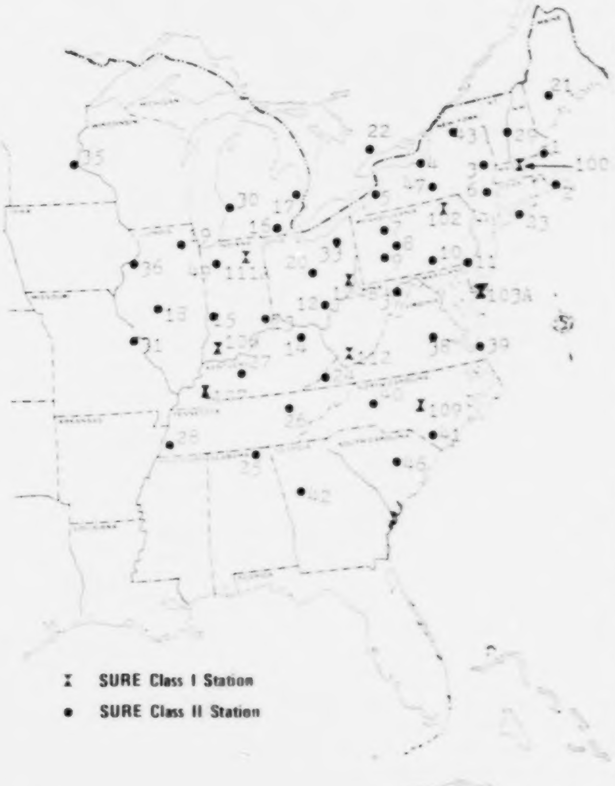

Figure 1. Ground stations throughout the northeastern United States.

Aircraft Program

SURE, for budget reasons, depends mainly on ground-based stations. Such a program has obvious disadvantages in that the third dimensional (vertical) component is missing. Transformation from SO_2 to sulfate occurs above ground level, hence SURE must have data from above the ground. The aircraft program is a compromise. Its goal is to give a 3-dimensional component to the ground measurements and yet stay within a fixed budget. The program will not solve the upper atmospheric question of chemical transformation. It should, however, define the vertical profile of pollutants at selected stations. Two airplanes will be used, each at a Class I station, during each of the intensive periods, i.e., four times a year. Each plane will fly three vertical spirals (from about 500 feet above ground level to 10,000 feet), one spiral at the Class I station, one 15 km upwind of the station, and one 15 km downwind. The three spirals will be flown both morning and afternoon. This program of two flights per day (for each plane) will be repeated six days during an intensive period with the restriction that no flights be made on successive days. The program is not aimed at flying during specific episodes or at tracking air masses. Its goal is routine measurement at Class I sites. Sites have not yet been selected nor has a decision been made as to the possibility of changing sites during the program. Basically the airplane program (Appendix A) will involve the same measurements as those made on the ground.

Emissions Inventory

Critical to the fundamental objective of SURE is an adequate emissions inventory. Inventories will be prepared for four pollutants: (1) oxides of sulfur, (2) oxides of nitrogen, (3) total emitted particulate matter, and (4) non-methane hydrocarbons. Sources will include: (1) fossil-fueled electric power plants, (2) other major industries, (3) non-manufacturing and business (commercial), (4) homes, and (5) surface transportation. All source inventories will be presented as seasonal averages (e.g., June-August) for each of the eight 3-hour periods during a day. For example, SO_x emissions calculated from an individual power plant during summer will yield eight numbers for that plant, the eight representing the average emissions from midnight to 3 AM, 3 AM to 6 AM, and so on. The basic inventory will be for sources in existence in July 1977. Calculations will be updated for July 1978 sources.

Modeling

The measurements part of SURE will provide basic data on the distribution of pollutants. It will not, however, explain the formation and variation of pollutant levels in terms of source contribution and meteorological variabilities. In order to achieve this interpretative step, SURE also includes a modeling program which really comprises data analysis and simulation modeling. Data analysis and simulation modeling are inextricably intertwined but they can be broadly distinguished by considering data analyses as the development and testing of hypotheses regarding the component parts of, for example, the sulfate formation system. Simulation modeling attempts to integrate the component parts into a physical-mathematical representation which mimics the real world of sulfate formation. It should be apparent, from the general discussion of SURE, that some key elements (component parts) are missing if a realistic model is to be developed, namely the biogenic contribution to atmospheric sulfur levels, the chemistry of the SO_2- sulfate transformation, and the removal of sulfur species through dry deposition. Other programs supported by EPRI are aimed at elucidating some aspects of these key elements. Specifically, one project to measure biogenic emissions is already underway. A program of sulfur chemistry in plumes will begin in summer 1977. And plans are being formulated for a major study of dry deposition - to begin in 1978. The modeling effort will also take advantage of findings from non-EPRI projects, viz., the ERDA MAP3S program. Close coordination is being maintained between EPRI and a number of federal and state agencies.

Expected Results

Firstly, and most importantly, SURE will provide a vast amount of routine data on pollutant levels over a large part of the United States. The data will be carefully defined in terms of precision and overall quality control (Appendix A). They should be useful, therefore, for a number of independent studies for years to come. If nothing else were to develop from SURE, the data bank will be valuable as a contribution to the scientific community. It will contain numbers whose reliability can be specified. Secondly, SURE will yield a high-quality emissions inventory for the Northeast. Finally, a predictive model will be generated - a model which predicts the impact of emissions of a precursor on the ambient concentrations of a secondary pollutant. Admittedly, at this stage, we cannot judge what sort of error the estimate from the model will have but SURE will be developing a key model which looks at the important question of emissions and regional concentrations. We envision the SURE study as being important for: (1) answering, in part, the question of SO_2 control to meet ambient sulfate standards, (2) possibly re-evaluating use of supplemental control systems, and (3) serving as a guide to improved health-effects studies.

APPENDIX A

Data Recovery Criteria

Priority A - essential for the objective of SURE. 90% of the data must be recovered with a precision of ±10%.

Priority B - necessary for the objectives of SURE. 90% of the data must be recovered with a precision of ±10%.

Priority C - desirable for the objectives of SURE. 80% of the data must be recovered with a precision of ±10%.

Priority D - exploratory within the objectives of SURE. Recovery rate and precision to be specified individually when measurement program is approved.

Data recovery rate is defined as the percentage of the total number of possible observations which are actually recovered, and these must be within the precision limits.

Example: SO_2, a Priority A parameter, is to be measured for each consecutive 3-hour period for the duration of the SURE measurements program at Class I stations.

July 1, 1977 through March 31, 1979 = 639 days = 5112 3-hr periods

0.90 x 5112 - 4600 required observations/Class I station

Precision is defined as the percentage departure of a measurement from either its "true" value or from that of a primary standard when the measured value is greater than 10 times the threshold of detectability. When the measured value of the parameter is less than 10 times the measurement threshold, acceptable precision is defined by a linear decrease from 100% at the threshold value to the prescribed precision at ten times the threshold value.

Example: the threshold of detectability of SO_2 is 4 ppb. When 4 ppb are measured, the true value should lie between zero and 8 ppb. When 1.20 ppb are observed, the precision should be 52.8%, or the true value should lie between 9.4 and 30.6 ppb. When the observed value is 4.0 ppb, the true value should lie between 36 and 44 ppb. (±10%)

Any or all of the following techniques are to be used to assure the appropriate measures of data recovery and precision.

1. Detailed logs of instrument or analyses systems malfunctions and down-time for repair, calibration, or replacement.
2. Calibration of instruments or analyses systems against primary standards at suitable intervals of time.
3. Replicate in situ sampling and comparative analyses in sufficient numbers and ranges of conditions (parameter values) to assure statistical significance.

MEASUREMENTS AT SURE GROUND STATIONS

Parameter	Class I	Class II
SO_2 (Gas Analyzer)	Priority A Continuous measurement. Averaging time 3 hours	Priority A Continuous during intensives. Averaging time 24 hrs.
NO/NO_2 (Gas Analyzer)	Priority A Continuous measurement. Averaging time 3 hrs	Not measured
$SO_4^=$ (Hi-vol)	Priority A Continuous measurement. Averaging time 24 hrs	Priority A Continuous during intensives. Averaging time 24 hrs.
$SO_4^=$ (Seq. Sampler)	Priority A Continuous during intensives.	Not measured
NO_3^- (Hi-vol)	Priority A Continuous measurement. Averaging time 24 hrs	Priority A 8 days during intensives. Averaging time 24 hrs
NO_3^- (Seq. Sampler)	Priority A 8 days during intensives. Averaging time 3 hrs	Not measured
TSP (Hi-vol)	Priority A Continuous measurement. Averaging time 24 hrs.	Priority A Continuous during intensives. Averaging time 24 hrs
O_3 (Gas Analyzer)	Priority B Continuous measurement. Averaging time 3 hrs	Not measured
HC (C2-C12) (Cannister grab sample)	Priority B Continuous during intensives. Averaging time 3 hrs Continuous during non-intensives. Averaging time 24 hrs	Not measured

MEASUREMENTS AT SURE GROUND STATIONS (cont.)

Parameter	Class I	Class II
SO_3	Priority D 3 days during first intensive only. Averaging time 3 hrs	Not measured
RSP (<2μm)	Priority B Continuous during intensives. Averaging time 3 hrs	Not measured
Dew Point	Priority B Continuous measurement. Averaging time 1 hr	Priority B Continuous measurement. Averaging time 1 hr
Air temperature	Priority B Continuous measurement. Averaging time 1 hr	Priority B Continuous measurement. Averaging time 1 hr
PB, Fe, V and Mn	Priority C 3 days during intensives	Not measured
NH_4^+, Cl^- (Hi-vol)	Priority C Continuous measurement. Averaging time 24 hrs	Priority C 3 days during each intensive Averaging time 24 hrs (also includes NCC)
NH_4^+, CL^-, H^+, NCC (non-carbonate carbon) (Seq. sampler)	Priority C 3 days during intensives. Averaging time 3 hrs	Not measured

SURE AIRCRAFT MEASUREMENTS

Parameter	Requirements
SO_2 (Gas Analyzer)	Priority A Continuous measurement. Averaging height: 50 ft. Sfc - 5000, 100 ft. 5-10,000 ft.
$SO_4^=$ (Filter)	Priority A Continuous measurement. Averaging heights: Sfc-5000, 5-10,000 ft.
NO/NO_2 (Gas Analyzer)	Priority A Continuous measurement. Averaging height: 50 ft. Sfc - 5000, 100 ft., 5-10,000 ft.
TSP (dichotomous)	Priority A Continuous measurement. Averaging heights: Sfc - 5000, 5-10,000 ft.
O_3 (Gas Analyzer)	Priority B Continuous measurement. Averaging height: 50 ft. Sfc - 5000, 100 ft. 5-10,000 ft.
HC(C2-C12) (Cannister)	Priority B Grab sample Averaging heights: Sfc-5000, 5000-10,000 ft.
βscat, βext (Nephelometer)	Priority B Continuous measurement Averaging height: 100 ft. Sfc - 5000, 200 ft. 5-10,000 ft.

SURE AIRCRAFT MEASUREMENTS (cont.)

Parameter	Requirements
CN	Priority C Continuous measurement. Averaging heights: Sfc - 5000, 5-10,000 ft.
T, RH, q^2	Priority A Continuous measurement. Averaging height: 50 ft., Sfc - 5000, 100 ft. 5,000-10,000 ft.
Altitude, Airspeed Location, Time/Date	Priority A Continuous measurement. Time checks corresponding to height intervals of averaging for other parameters
NWS	Data to be archived
Rawinsonde	All available stations east of Mississippi River Two per day for 2 years
6-hr Airway Obs -	All available stations east of Mississippi River. Four per day for 2 years.
Hourly WxOB	All available stations east of Mississippi River during seven intensive measurements periods.
Special Obs	Upper air winds or aircraft measurements of wind, temp, and RH as available from ERDA program or others.

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THE MULTI-STATE ATMOSPHERIC POWER PRODUCTION POLLUTION PROGRAM

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The Multi-State Atmospheric Power Production Pollution Study (MAP3S) is a major atmospheric research program of ERDA's Division of Biomedical and Environmental Research (Fig. 1). The MAP3S program is one of several environmental programs being pursued under the Assistant Administrator for Environment and Safety, the activities of which were described in the First National Conference on the Interagency Energy/Environment R & D Program by Dr. James Liverman. MAP3S will ultimately provide improved capability to such programs as ERDA's National Coal Utilization Assessment, which is using present technical capabilities to assess the impact of future coal use.

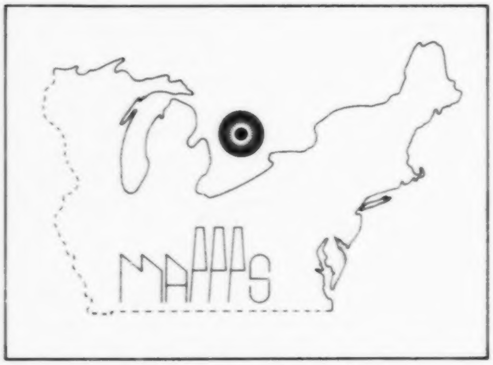

Figure 1. Multi-state Atmospheric Power Production Pollution Study.

The goal of the MAP3S program is to develop and demonstrate an improved, verified capability to simulate the present and potential future changes in pollutant concentration, atmospheric behavior and precipitation chemistry as a result of pollutant releases to the atmosphere from large-scale power production processes, primarily coal combustion (Fig. 2). A major motivation of this program is to be able to provide those agencies charged with the task of meeting the nation's energy needs with the knowledge required to assess alternative strategies for generating power while ensuring ample protection of human health and adequate preservation of the natural environment. Since coal is the most abundant domestic fossil-fuel resource and since electric power production is a major and growing sector of our energy economy, this study focuses on the effects of emissions from coal-fired electric power plants, particularly in the high population, energy intensive northeastern quadrant of the United States. The improved capabilities and numerical models will be made available for use in regional studies and assessments.

Improved simulation capability (model)

- Develop
- Verify
- Demonstrate

For use in evaluating present and future effects

- Air quality
- Precipitation chemistry
- Atmospheric behavior (visibility, etc)

Due to power production emissions

- Primarily coal combustion
- Primarily sulfur oxides
- Northeastern United States

Figure 2. MAP3S goal.

MAP3S participating organizations (Fig. 3) will focus their research efforts on providing understanding of the atmosphere's effect on pollutants. In recognition of the widespread interest in and research on these pollutants, our program will coordinate with the major ongoing and proposed programs of EPRI, EPA and other organizations in order to ensure a comprehensive national program. Through such coordination, we hope to achieve greater understanding of how coal can be used to meet the nation's energy needs while maintaining environmental quality and protecting human health.

Experience and expertise

ERDA national laboratories
- Argonne
- Battelle Pacific Northwest
- Brookhaven
- Health and Safety Laboratory
- Lawrence Berkeley Laboratory

Other Organizations
- Illinois State Water Survey
- Universities (SUNY, Cornell, PSU, U. VA., BYU, etc)

Cooperation and coordination

EPA and other U.S. government agencies
Electric Power Research Institute
Atmospheric Environment Service (Canada)

Figure 3. MAP3S resources and capabilities.

The charge to the MAP3S program encompasses the entire spectrum of atmospheric pollutants that may be ascribed to fossil-fuel electric power production, including:

- Sulfur dioxide, sulfites, sulfates, and other sulfur oxides.
- Nitrogen oxides and their secondary reaction products, including oxidants.

- Hydrocarbons, including polycyclic organic matter.

- Trace inorganic elements.

- Particulates, which may contain any or all of the above substances as well as elemental carbon or soot.

However, in view of this wide range of pollutants and the many associated atmospheric processes and recognizing resource constraints, a number of reasons have led to assigning priority to the study of sulfur oxides and their associated cations during the present phase of the MAP3S program. These reasons include:

- Sulfur oxides are a major pollutant from coal, the use of which will increase.

- Potential health and environmental consequences of sulfur oxides are of present concern.

- Anticipation that an ambient air quality standard for sulfate will be set in several years.

- Coordination with other sulfur-oriented programs.

- Techniques developed for simulating the sulfur cycle should be transferable to study of other compounds.

- Need to focus research efforts.

- Building on experience of previous research.

MAP3S RESEARCH PROGRAM

Development of the assessment (i.e., numerical modeling) capability needed for accurate assessment of the human health and biological implications (e.g., dose-to-man and dose-to-ecosystems) of sulfur oxides requires an understanding of the source, transport, transformation and sink processes. Thus, the MAP3S research program has been divided into the ten interrelated program elements, or tasks, described below. Each task focuses attention on an area of significant uncertainty.

The core budget for the MAP3S program in FY-77 totals approximately \$3,000,000. An approximate percentage breakdown of the \$3 M by MAP3S task is given in Fig. 4.* The major efforts are seen to be characterization of the region and its pollutants; studies of transport, transformation and precipitation chemistry/scavenging; and numerical modeling. The research emphasis for the next several years is expected to remain nearly the same, although specific research activities will continue to evolve to address the most uncertain program elements.

(~ \$3M, FY-77)

Task 1:	Power plant emissions	2.5%
Task 2:	Other related emissions	
Task 3:	Pollutant characteristics	10.0%
Task 4:	Pollutant distribution	15.0%
Task 5:	Vertical and long-range transport	10.0%
Task 6:	Pollutant transformation	20.0%
Task 7:	Dry deposition	2.5%
Task 8:	Pollutants and precipitation	15.0%
Task 9:	Weather and climate effects	10.0%
Task 10:	Numerical modeling	15.0%

Figure 4. MAP3S research program.

We are also striving to interface with the health, ecology, and assessment studies within ERDA, funding for which is additional to the figure given above. These studies include toxicology studies at the Inhalation Toxicology Research Institute, Oak Ridge, and Battelle Northwest, among others. The ecological effects of acid rain on crops, ferns and tree seedlings are being studied at Argonne, Brookhaven and Oak Ridge.

MAP3S RESEARCH TASKS

Task 1: Specification and quantification of the emissions of atmospheric, energy-related (AER) pollutants resulting from present power production processes and consideration of the spectrum of pollutants that may be emitted as a result of introduction of new processes.

The Brookhaven National Laboratory (BNL) under both ERDA Regional Energy Studies and MAP3S funding has used existing FPC, NEDS and state emission inventories to develop an emissions data base including nearly 500 point sources (not all of which are power plants) in the eastern United States. The inventory includes sulfur and nitrogen oxides, hydrocarbons and particulates. Considerable cross-checking of information is now underway and inclusion of sources in the province of Ontario will be started in the near future. Comparison of this inventory with other emissions data bases is encouraged.

Task 2: Identification and quantification of sources of AER pollutants that do not result directly from power production and of other substances that may affect the concentration, distribution, transformation and fate of AER pollutants.

The BNL effort discussed in Task 1 is also developing an area source inventory, since studies in urban plumes indicate sulfate formation can be intensified in the presence of other pollutants. An inventory of other emissions in the eastern United States is underway; presently about 10,000 small point sources are aggregated into elements, each roughly 30 by 30 km. Emissions from the biosphere are not included, although efforts are underway to identify potential source regions (e.g., marshlands) by identifying land types. Work in this area by EPA and EPRI will be followed.

---

*Most of the funding for Task 9 is for completing METROMEX analysis and will be transferred to Task 8 in FY-78 for precipitation chemistry analysis around Chicago.

Task 3: Characterization of the physical and chemical properties of AER pollutants, including particle size, oxidation state, derivative compounds, molecular form, etc., which are commonly found in the atmosphere on a regional scale.

In order to both understand atmospheric transformation mechanisms and to provide needed information for health studies, a number of approaches are being pursued to identify properties of atmospheric compounds (Fig. 5). ANL has already located Lundgren impactors at Penn State University, the University of Virginia, and BNL and will field at least one more in order to determine regional patterns of particle acidity by infrared spectroscopy (four hour samples are being taken, every fifth one being routinely analyzed). Method intercomparison studies for particulate sulfur analysis are underway between Gran titration, thermometric titration, infrared spectroscopy, XRF, and others. We have been participating in a field intercomparison study involving ERDA and EPA in Charleston, West Virginia.

(MAP3S program)

Ion chromatography

X-ray fluorescence

Methyl-thymol blue

Silver-110 (^{110}Ag) precipitate

Gran titration

Infrared spectroscopy

Benzaldehyde extraction

Thermochemical titration

Photo-electron spectroscopy

Figure 5. Particulate sulfur analysis techniques.

Task 4: Determination of the spatial and temporal distribution of AER pollutants under both average and extreme conditions.

MAP3S will rely largely on the SURE network for information on surface pollutant concentrations. An initial quality assurance program is being planned by the Health and Safety Laboratory (HASL) in order to intercompare analysis methods and assure sample integrity. Major MAP3S effort will be devoted to using aircraft to determine the distribution of pollutants above the surface. MAP3S will be commiting two aircraft to taking such measurements during the first SURE intensive period (planned for early August). Further meetings between SURE and MAP3S project participants are being planned to lay out flight plans, schedules, and needed coordination.

Task 5: Determination of the processes and parameters governing the vertical and horizontal transport of AER pollutants.

Because sulfates remain in the atmosphere for several days, they become involved in both the diurnal cycle of the surface mixed layer and the movement of the air over long distances. Building on ANL's studies in Sangamon County, Illinois, a "box budget" experiment is being planned for this fall to determine the fluxes and transformation of atmospheric sulfur compounds in aged, polluted air. Aircraft and surface measurements, and possibly a tracer experiment, are being planned in order to follow the vertical mixing through the daily cycle, dry deposition at the surface, and horizontal transport.

Studies of long distance horizontal transport require use of inert tracers which can be detected at very low concentrations. A joint ARL, HASL, LASL, and BNL field experiment (out to 90 km) was recently completed in Idaho Falls to intercompare five tracers (SF_6, two deuterated methanes and two perfluorocarbons) and to field test the new perfluorocarbon detection instruments developed by J. Lovelock. Analysis is now underway and future plans for use of these tracers in MAP3S are being evaluated.

Task 6: Identification of the chemical and physical transformation processes affecting AER pollutants and determination of the rates and mechanisms controlling these processes.

The MAP3S program is focusing on field measurements of reacting point source and urban plumes in order to deduce the rates and mechanisms of chemical transformation. BNL has recently sampled the AnClote (Florida) power plant plume by aircraft while EPA made stack emission measurements and MRI (for EPA) sampled by aircraft. Comparison of results should help resolve discrepancies that have arisen in previous studies concerning SO_2 transformation rates. PNL will also be undertaking plume studies for EPRI in the coming year.

Results from last August's study of the Milwaukee urban plume are now being analyzed (Fig. 6). Three methods for determining sulfate and two for SO_2 were on board the PNL aircraft and intercomparisons are underway. Other measurements of the molecular character of the particles, hydrocarbon composition (by EPA), and other pollutants (by a NASA aircraft) are being assembled. Early results indicate that ozone and sulfate are forming as the air mass ages (Fig. 7), while SO_2, NO, and NO_2 are decreasing. Layers of increased sulfate concentration were also found at about 3000 m on days when the wind was from the northeast, perhaps indicative of long range transport. Further experiments are being planned for this summer in the same region, the Milwaukee plume being particularly interesting because of its isolation from other sources and the stable layer that isolates it from the lake surface.

Direct mechanistic studies have also begun at ANL in which determination of the oxygen isotope ratio in SO_2 and sulfates is used to determine the chemical paths that occurred during transformation processes. Laboratory testing of the technique has been augmented by analysis of field samples.

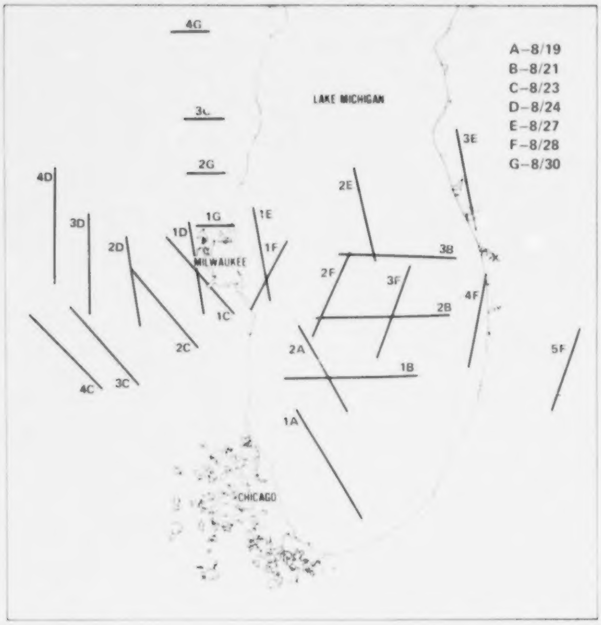

Figure 6. DC-3 aircraft flight routes for Milwaukee urban plume study.

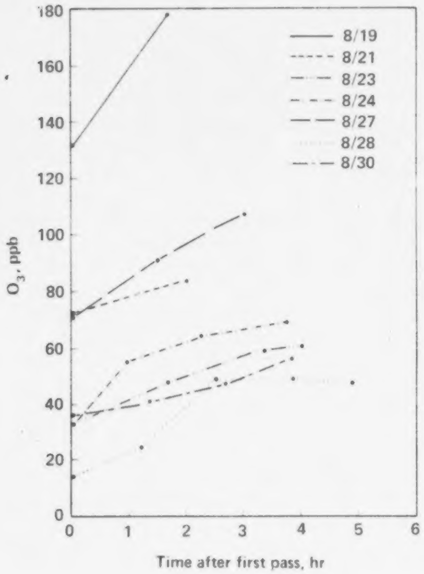

Figure 7.

Averages of ozone concentrations in the Milwaukee urban plume.

Task 7: Determination of the rates of physical and biochemical mechanisms governing the removal of AER pollutants from the atmosphere at the earth's surface (dry deposition).

ANL is leading a cooperative ERDA-EPA program to use eddy-correlation techniques and fast-response pollutant instrumentation to measure directly the dry deposition of pollutants over various types of terrain. Tested originally over soybean and corn fields (Fig. 8), the experiment this summer will move to a forested area near Research Triangle Park, N. C. and then to areas with other vegetation and terrain characteristics.

Figure 8. Meteorological instrumentation for planetary boundary layer study.

Task 8: Identification of the mechanisms and rates governing the removal of AER pollutants by precipitation scavenging (washout) and by in-cloud processes (rainout) and determination of the effects of AER pollutants on trace material balances and precipitation chemistry, specifically including the acid-base relationships.

Determination of the chemical characteristics of present precipitation in the Northeast is being investigated by establishment of a regional precipitation chemistry sampling network. Stations have been established near Whiteface Mountain (N. Y.), Cornell, Penn State, and the University of Virginia. Results from about four months of sampling are now available. Sites for four to eight additional samplers are being considered and should be operational by mid-summer (Fig. 9). Results from HASL (bucket) and PNL (funnel) samplers are being compared, especially for concentrations of trace metals. If comparisons are favorable (as expected), the HASL samplers (which may not be accurate for volatile compounds) may be switched to a weekly basis rather than a storm event basis in order to allow calibration with the proposed USDA regional network. Rain collected by a finer scale network being established around Chicago and lower Lake Michigan by the Illinois State Water Survey (for NSF, Illinois and the City of Chicago) will be analyzed for chemical properties beginning in early 1978 in order to identify metropolitan effects on precipitation.

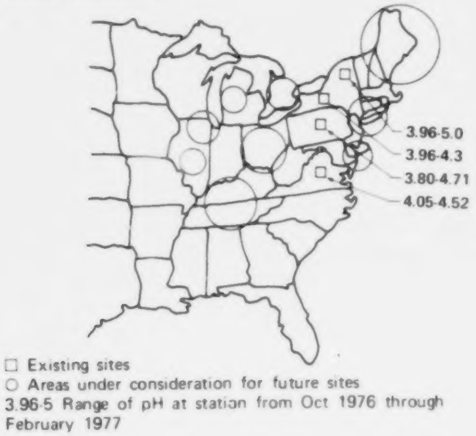
3.96-5.0
3.96-4.3
3.80-4.71
4.05-4.52
☐ Existing sites
○ Areas under consideration for future sites
3.96-5 Range of pH at station from Oct 1976 through February 1977

Figure 9. **MAP3S precipitation chemistry network.**

The second aspect of the program involves study of the precipitation mechanism by measuring various quantities in and around storm systems. An exploratory field program this March investigated stationary lake effects storms downwind of Lake Michigan. Data were collected by aircraft during two storm days and at the surface during seven storm days. Additional clear air flights and snow core collection also took place. This coming winter an expanded experiment using PNL's DC-3 and an NCAR aircraft is being planned to look at the scavenging of pollutants in snow storms.

Task 9: Determination of the effects of AER pollutants upon weather and climate, including effects on visibility, radiation transport, and the amount and extent of precipitation.

We are hopeful NSF programs will carry most of the research load in this area. The MAP3S effort is now limited to the establishment of a regional pyranometer network and the completion of analysis of METROMEX results. Presently nine of eleven pyranometer stations are operational, the final two expected to be on-line in early summer. By measurement of the direct and diffuse components of radiation, we anticipate being able to provide some of the fundamental information needed to determine if pollutants are significantly affecting the energy balances of the surface and lower atmosphere.

Task 10: Development, verification, and demonstration of methods (numerical models) which will make possible accurate assessment of the atmospheric transport and transformation of AER pollutants and of various strategies for generation of energy while minimizing atmospheric pollution.

MAP3S is supporting development of both trajectory and grid models in order that the advantages of each technique can be fully pursued. Trajectory model research includes that at NOAA-ARL on providing vertical resolution in such models; at PNL (Fig. 10) in evaluating the sensitivity of model results to data input (e.g., height of wind use, episodic versus average precipitation, etc.) and parameterization techniques; and at ANL on use of statistically averaged trajectories for use in calculating time averaged pollutant concentrations. ANL is also developing a grid model, focusing their attention on representation of changes in the depth of the mixed layer. At BNL, in addition to a trajectory model, a particle-in-cell model is being used to simulate regional sulfate levels based on the emission inventory described earlier (Fig. 11). The wind field and mixing parameters for the model are coming from a variational analysis model which accounts for the complex terrain in the northeast. A centralized data base for the MAP3S program is being established at BNL to support the modeling efforts and to provide data to other interested groups.

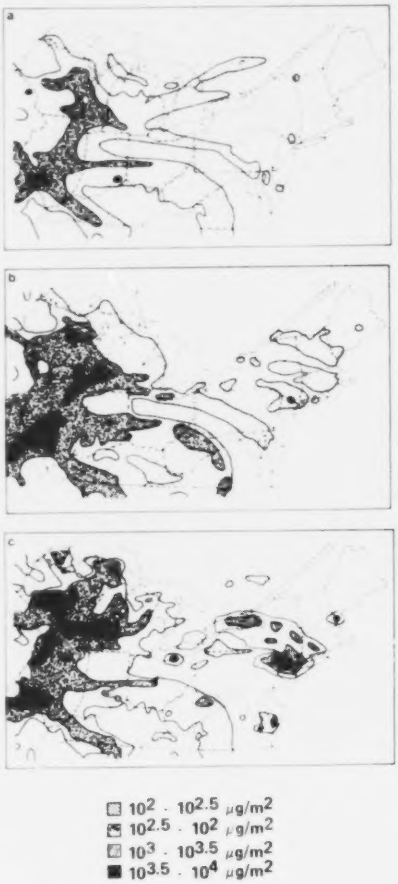
a
b
c
10^2 - $10^{2.5}$ μg/m^2
$10^{2.5}$ - 10^2 μg/m^2
10^3 - $10^{3.5}$ μg/m^2
$10^{3.5}$ - 10^4 μg/m^2

Figure 10. **Sulfate deposition by dry and wet deposition.**

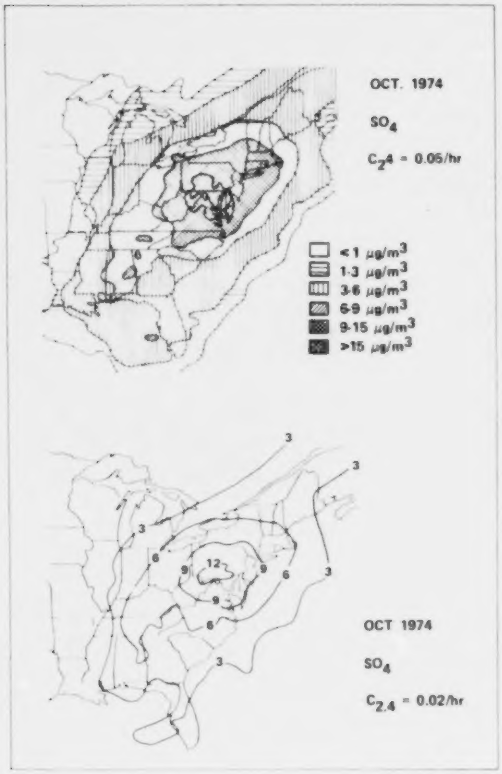

Figure 11. BNL trajectory model simulation of sulfate concentrations.

CONCLUSIONS

While the range of activities sponsored by the MAP3S research program is quite broad, the problem of sulfur oxides in the atmosphere is very complex. The research needed to provide the knowledge and understanding necessary to develop effective regulations will require the efforts of more than just ERDA, just EPA, or just EPRI. By coordinating our research activities and those of other organizations, particularly with regard to the very expensive monitoring, characterization and field programs, we are hopeful that a comprehensive scientific effort can be pursued that will allow each organization to have sufficient information to undertake assessment and interpretive studies.

Discussions between ERDA, EPA and EPRI have already borne fruit; joint planning and joint funding are taking place on some projects; EPA and ERDA are commenting on each other's plans; and an international symposium this fall is being co-sponsored by EPRI, EPA and ERDA. Contacts with the Atmospheric Environment Service of Canada indicate that the border need not hinder scientific cooperation. To assist in keeping others up-to-date on MAP3S activities, a quarterly newsletter is being sent to over 300 interested organizations and individuals.

Pollution from power production is an important research topic, especially in view of the planned increased reliance on coal. Through research sponsored by ERDA and other organizations, we anticipate that the necessary knowledge will be provided to those agencies charged with meeting the nation's energy needs to allow assessment of alternative strategies for generating power while ensuring ample protection of human health and adequate preservation of the natural environment.

ACKNOWLEDGMENT

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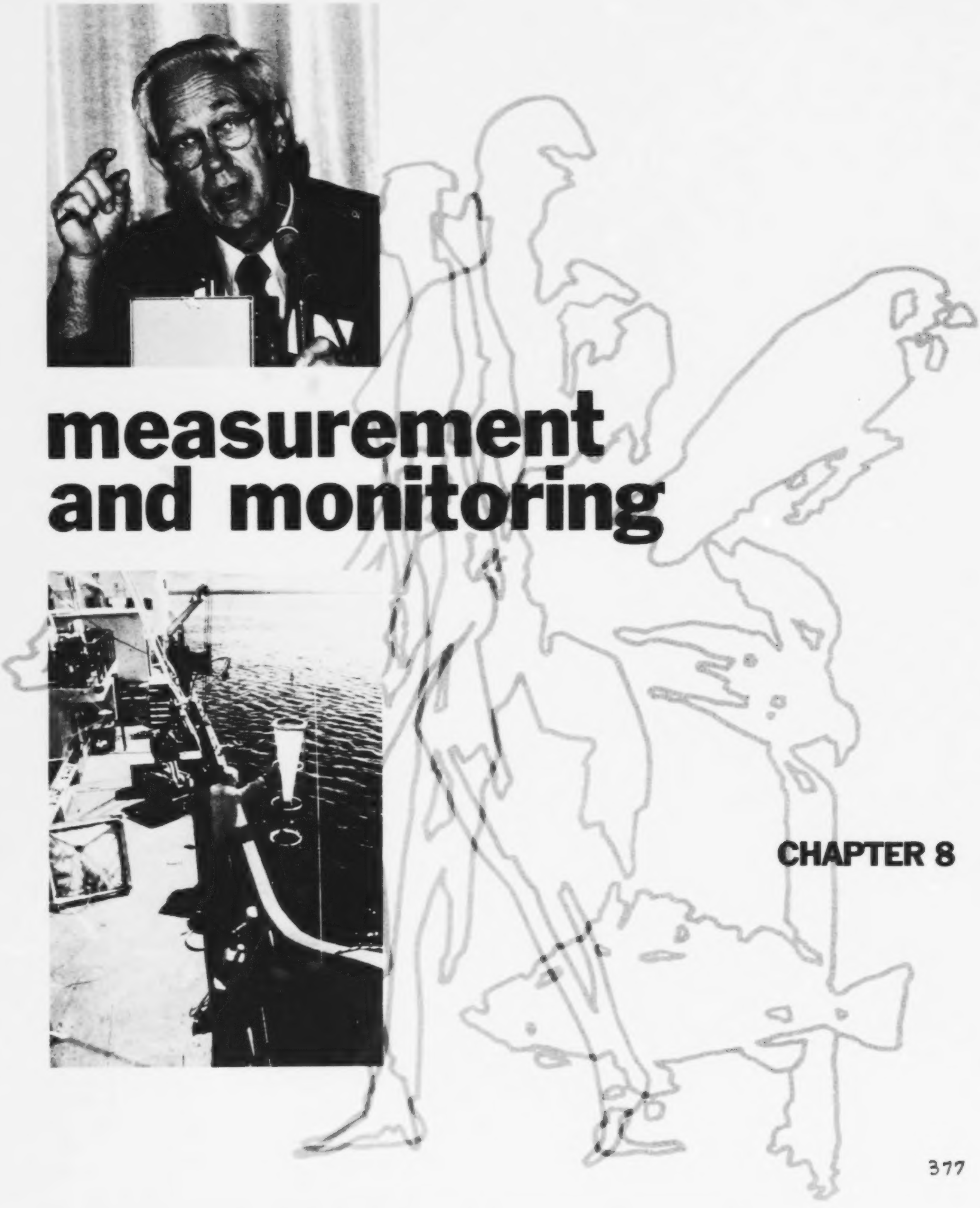

measurement and monitoring

CHAPTER 8

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measurement and monitoring

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MEASUREMENT AND MONITORING

George B. Morgan
Director
Environmental Monitoring and Support Laboratory
U.S. Environmental Protection Agency

INTRODUCTION

Adequate control must be imposed upon energy resource development so that environmental pollutants can be kept to an acceptable level. The objective of environmental pollution control is to prevent the adverse effects of pollutants. To achieve this objective, we need several types of information. First, we must establish the relationship between exposure of the critical receptor to and effects from the pollutants. Second, we must know the relationship of the total exposure to which the receptors are subjected and the sources. And finally, once controls are implemented, we must evaluate their effectiveness in maintaining the exposure levels at an acceptable concentration.

To determine the types of information necessary, monitoring and measurement systems and techniques are essential. The information presented in this paper summarizes 18 papers from 9 different Federal agencies. It is truly a multimedia, interdisciplinary approach toward evaluating the total effects of energy development upon our environment. Through such an interagency effort, it is possible to develop a compatible data base to determine the source, transport, and fate of environmental pollutants. Only from such a compatible data base can logical decisions be made as to types and strategies for energy resource development.

MONITORING

The Western Air Quality Monitoring and Western Water Quality Data Integration Projects conducted by EPA are designed to provide integrated and validated monitoring data (baseline and trend) and assessment reports for the western areas of the United States which are, or will be, the most seriously impacted by present or projected energy-related development activities. In the air monitoring area, emphasis is placed on fine particulates, NO_x, SO_x, reactive hydrocarbons, toxic substances, and visibility. The geographical coverage of studies to be conducted under this project includes the Northern Great Plains, the Four Corners area, oil shale areas of Colorado and Utah, the Black Mesa area of Arizona, and areas of New Mexico. It is quite obvious that continued and accelerated development of the various energy resources in the West potentially impact the environmental quality of these regions.

The air quality monitoring network in the Western Energy Resource Development Area (WERDA) now consists of 474 stations. Depending on the analysis desired, these stations are categorized according to the surveillance classifications of the sampling site—that is, population, source, or background. Less than half of these stations are located in rural areas and related to background monitoring sites.

Under the Interagency Energy Program, significant progress has been made to identify and expand the air quality monitoring networks. For example, 77 sites have been added throughout the 8-state region for sulfate and nitrate analyses. The Ute Research Laboratory network is also being used to collect samples for trace element analysis—that is, iron, cadmium, chromium, copper, lead, cobalt, manganese, nickel, and molybdenum.

Visibility deterioration, probably the first observable impact on air quality from energy development and related activities, is not presently being quantitatively measured. We are proposing a network of visibility monitoring stations. Tentative sites for these stations have been selected.

A major advancement, following the air quality monitoring data to be used for the regional scale assessments, has been made through the initiation of a quality assurance program. Seventeen participating laboratories, including Federal, State, private, and contractor, are involved in a uniformly applied, audited, cross-check program that permits all data to be entered into the Soroad data base.

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The accelerated energy development in WERDA is in direct competition with other users for the limited available water resources. Extraction of raw materials, fuel refinement, transport, utilization, and the accompanying demographic changes will place additional demands on available water. Loss of water through evaporation, absorption into process waste streams, and exportation to other regions is only one area where water resources may be affected by increased development activities.

EPA WATER QUALITY PROGRAM

In response to the need for baseline data by which to assess the impact of energy development activities, the U.S. Environmental Protection Agency has initiated a water quality data integration program. Participating with the EPA are elements of the U.S. Geological Survey. Several other Federal, State, and local agencies are also cooperating in the study.

The specific objective of the program is to establish a base of biological, chemical, and physical information which will serve (1) as a baseline upon which alterations to water quality can be assessed, (2) as a basis for relating pollutants and/or effects to specific activities, and (3) to provide input to the energy and environmental planning process.

Information on energy resource development and data regarding existing facilities, together with existing and anticipated pollutant speciation, locations, and concentrations data, were used to identify a network of water quality monitoring stations in the WERDA. Over 200 currently active, data-rich (25 or more parameters monitored for a period of at least 2 years) surface-water monitoring stations were selected for this network. Other stations and those of special studies are incorporated as necessary to fill specific data gaps. Data gathered are coded into STORET, EPA's water quality data base, and are retrieved for statistical analyses, listings, and summarizations. Also, a quality assurance program has recently been initiated which includes site visits to participating laboratories and performance audits using periodic check samples.

There is a problem with the relatively large amount of data to be reviewed and assessed. This problem is compounded by the ephemeral nature of the Western water resources. Many streams to the major waterways are seasonally intermittent; flow in others is intermittently surface and subsurface.

USGS WATER QUALITY PROJECTS

The Water Resources Division of the U.S. Geological Survey operates a network of 6,200 water quality monitoring stations nationwide. Of these, 590 are in the Rocky Mountains and Northern Great Plains States of Colorado, Montana, North Dakota, New Mexico, Utah, and Wyoming, of which 73 are funded partially from EPA funds. EPA funds provide for collection and analysis of a broader set of water quality parameters than that normally obtained by the USGS. These data are used to establish baseline water quality, sediment, and flow conditions against which future assessments of impact can be made. The report submitted by USGS includes reports obtained from 3 of the 22 projects involved in the interagency program.

DETERMINATION OF WATER QUALITY

One of the projects is to determine the quality of water in the Chaco River Basin of New Mexico. In this area is located the Four Corners Power Plant and its associated Navajo Coal Mines, as well as the San Juan Power Plant. Both are considering expansion. The Western Gasification Company's proposed gasification plant and the El Paso Company's proposed gasification plants will also operate in this area. The major water users will derive their water supplies from the San Juan River system. As much as 500,000 acre feet of the annual average total of 1.6 million acre feet, as measured on the San Juan River at Shiprock, may be diverted for these projects. Available data on the quantity and quality of the water resource in the Chaco River Basin are very sparse. The impact of energy development, particularly on water quality in the Chaco Basin and ultimately downstream in the San Juan River and Colorado River, must be assessed. Data collected to date represent baseline and present water quality conditions of both surface and ground water resources. This will help to determine the effects of proposed energy development in the area. Both sources of water are extremely hard, with the hardness derived from calcium sulfate.

Another USGS project is studying the effects of acid mine drainage in southeastern Ohio. The first phase of this study was a reconnaissance of water quality at 162 sites to document the severity of the acid mine drainage problem and to pinpoint affected streams. The second phase involves a more comprehensive water quality sampling program. Phase II objectives include determination of source and chemical quality of water in each tributary, evaluation of influence of tributary conditions on mainstream water quality, and determination of material loading of streams and tributaries. Data to date indicate a noticeable contrast in the data for an area of abandoned mines and an area where reclamation had been practiced. The absence of acid drainage from reclaimed and working strip mines emphasizes the importance of rapid reclamation in the prevention of acid drainage.

A third USGS project is to determine water quality in the oil shale areas of western Colorado. The latest developments in oil shale industry indicate increased interest in the modified *in situ* approach. The objective of the basic data collection program is to obtain water quality data needed to define predevelopment conditions and to monitor the effects of construction and operation of oil shale mines, retorts, and spent shale disposal areas. Data have been collected and summarized from 22 wells penetrating the 3 geological units likely to be involved in any *in situ* development.

MINING IMPACTS ON GROUND WATER QUALITY

An important concern of the EPA is impact of western coal and oil shale developments on ground water quality and the manner in which these impacts should be monitored. An EPA project to provide these answers is currently underway. The areas for study were selected where extensive development was being projected—that is, Campbell County, Wyoming, and the oil shale tracts UA and UB in northeastern Utah.

Ground water availability and usage can usually be determined without much difficulty. Impacts on ground water quality from mining, however, are much more difficult to assess. A typical misconception is that the baseline or background monitoring systems can also be used to assess the impact of man's various activities on ground water quality. This is not true in most cases of subsurface pollution. Many years and even decades may pass before change in ground water quality is observed. Once degradation of the subsurface regime has taken place, it is extremely difficult and costly to remedy. The EPA approach to this problem is to systematically monitor potential sources of pollutants before they enter the subsurface or the less accessible water itself. EPA has developed a predictive methodology for monitoring ground water quality. Over the next year, we plan to collect, organize, and interpret the background data for each potential pollution source.

POLLUTANT SOURCE PRIORITIZATION REPORT

At the end of the first year, a pollutant source prioritization report will be completed for each project area to identify the pollution sources needing the most detailed monitoring. Also at the end of the first year, another report will be completed, detailing oil shale mining approaches—Keregen recovery processes and hydrogeneration processes. Following this report by 3 to 6 months will be a monitoring program designed for the coal mining aspects. A similar monitoring program design for the oil shale mining and processing operations is expected in 18 to 24 months. We expect to have operational monitoring networks established for both oil and coal within 24 to 30 months.

An additional research need concerning the oil shale aspect of the project has been identified. The oil companies operating in tract CA, which is near tract CB in Colorado, have announced plans for oil shale development. Also, oil companies in tract CB have announced that they have developed an *in situ* process for the processing of oil shale. Monitoring for potential ground water quality impact associated with *in situ* oil shale development will be difficult. A proposal for expanding the monitoring method has been prepared and is awaiting approval and funding by EPA.

NASA AND EPA 5-YEAR PROGRAM

In the summer of 1975, NASA and EPA entered into a 5-year program entitled "Western Energy Related Overhead Monitoring Project" for the purpose of transferring hardware and software techniques for processing remotely sensed digital data. The project has been divided into three phases. Phase I was an 18-month period during which NASA capabilities were applied to processing digital data acquired by both Landsat and aircraft over coal strip mines in the Western United States. Following evaluation of the hardware and software for this capability, a data processing system was developed, assembled, and transferred to EPA/EMSL-LV in January 1977. The system has been installed and key EPA personnel were trained in the use of the data processing system during November and December 1976.

Recommended analysis procedures and multispectral data applications were documented in the NASA/ERL Report entitled "Western Energy-Related Overhead Monitoring Project Phase I: Summary of Activities July 1, 1975, through December 31, 1976." The report is presently being reviewed by EPA to determine the application and effectiveness of the suggested procedures. During Phase II of the project, recommended procedures will be applied, verified, and evaluated using current data sets as well as future data sets made available through an intensive field program now underway. Research and development activities continue, in parallel with evaluation of new procedures for solving complexities associated with data processing of strip mining activities. These procedures, which are now being tested by pilot studies, will result in state-of-the-art procedures converging into a final set of recommendations and future requirements.

SO_2 EFFECTS ON VEGETATION

A project underway in the Air Quality Branch of the TVA is entitled "Remote Sensing of Sulfur Dioxide Effects on Vegetation." The objective of this project is to test, refine, and develop remote sensing instrumentation and techniques for surveillance of SO_2 effects on vegetation in the vicinity of power plants. The work involves gathering and analyzing spectral reflectance data using imaging and nonimaging sensors and an array of instrument platforms, including cherry pickers, helicopters, and airplanes. Progress to date has been primarily in establishing procedures based upon past experimentation and determining plant damage following SO_2 exposure. During 1977, selected crops and trees will be subjected to fumigation of SO_2 under controlled conditions. These plants will be examined by photographic recording and image analysis, spectroradiometry, and image acquisition from airborne sensors and cherry pickers, with subsequent image analysis. The laboratory fumigation and photography of the affected plants are presently in process. The field spectroradiometer operations and overflights will occur in mid-summer 1977 when crops and trees are most susceptible to the effects of SO_2. Work during the post-1977 period will concentrate upon remote sensing, using satellite data. Currently available satellite imagery does not show promise for detecting subtle SO_2 effects on vegetation because of the limitation in image resolution. It is too soon to draw conclusions on the value of ongoing laboratory fumigation, chamber photographic experiments, color image enhancements, and spectroradiometric measurements. By late 1977, these experiments should be completed and several remote sensing overflights should have been conducted.

INSTRUMENTATION

EPA is conducting a project to develop pollutant measurement methods. The primary concern of this project is those pollutants associated with the burning of coal, including sulfur oxides, or more specifically sulfur dioxide, sulfation, and free sulfuric acid. The organic products of coal combustion that may be described as carcinogens or, more broadly, materials of high physiologic impact are included. Existing methods for measurement of sulfates in airborne particulates have long been known to be subject to interference.

AIR MEASUREMENT METHODS R&D

Sulfuric acid is known to be extremely reactive. Therefore, its successful measurement must be accomplished in something approaching real time. Collection on a highly inert filter, followed by rapid analysis, has been selected as the potentially feasible approach. Separation, identification, and eventual quantification of desired individual compounds from the incredibly complex mixture of organic materials generated by the combustion of coal is being attempted by combining in a synergistic fashion the separative resolution of gas chromotography, the analytic capability of mass spectrometry, and the recognitive skills of the computer. This appears the only feasible technique in today's state-of-the-art measurement.

One aspect of the ongoing research is leading toward development of a hypersensitive SO_2 instrument with a sensitivity of approximately 0.1 ppb. This flame photometric analyzer, capable of operating aboard a small aircraft, is expected to be available by January 1978. A method developed for microdetermination of sulfate and of strong acid has been modified and further improved.

A technique has been developed for collecting small particles on a fluorocarbon membrane filter, followed by analysis by X-ray fluorescence spectrometry. This method has the advantage that it maintains separation of sulfuric acid from other particulate matter, therefore permitting selective analysis.

Tenax GC, a thermostable porous polymer, has been demonstrated to be capable of retaining the vapors of nonpolar substances very efficiently and of releasing them upon heating. This has become the favored method of sampling for organic vapors in the atmosphere. Samples collected by this method are thermally transferred to a gas chromatography column and the column effluent is passed into a mass spectrometer for resolution.

STANDARD REFERENCE MATERIALS– AIR POLLUTION

The National Bureau of Standards (NBS) project entitled "Standard Reference Materials, Instrumentation and Methods for Energy Related Air Pollution Monitoring" is directed toward providing standard reference materials concerning gaseous pollutants and airborne particulates arising from fossil fuel combustion and from chemical extraction of fuels and raw materials. In addition, a project has been initiated to develop a method of distinguishing specific sulfur compounds in particulates derived from gaseous sulfur compounds.

Four standard reference materials for source monitoring have been issued. These consist of gas blends of SO_2 in nitrogen concentrations ranging from 500 ppm to 2,500 ppm. Other standard reference materials currently under development are NO_2 in air at concentrations ranging from 250 ppm to 2,500 ppm, oxygen in nitrogen, and hydrogen sulfide in a hydrocarbon gas blend. Other standards being developed for ambient air monitoring are carbon monoxide in air and gas blends of SO_2 and NO_2 in nitrogen. These standards are being investigated as alternatives to the NBS permeation tubes.

PARTICULATE PROJECTS

Because of the chronic effect of particulates on health, several particulate methodology projects are underway. Prototype standard reference materials for X-ray florescence analysis of particulates have been developed. These standards are developed by thermally evaporating thin metallic films onto polycarbonate filters and by sputtering glasses containing known quantities of trace elements with an argon ion beam onto polycarbonate filters. Another approach is to use fully characterized glass microbeads to simulate real particles.

Two instruments have been developed for particulate monitoring. The first is for measuring the size distribution of particles of known density. This instrument will be used to characterize aerosol generators. The second is for measurement of sulfur in particulate matter. The principle of operation is the combination of an electrostatic precipitator with a flame photometric detector. Another method is being developed to distinguish the sulfur compounds in particulates by thermally evaporating the compounds. This procedure takes advantage of the fact that different compounds vaporize at different temperatures. Work is underway to provide standard reference materials for elemental analysis of fuels and raw materials, for example, Western and Eastern coal.

NIOSH ENERGY RELATED RESEARCH

The Measurement Systems Section of the National Institute of Occupational Safety and Health (NIOSH) is presently conducting a project entitled "Energy Related Research Program in the Measurements Research Branch." There are six areas in this energy project.

1. A portable, battery-operated, fibrous aerosol monitor has been successfully developed. This instrument counts individual fibers of asbestos or fibrous glass in real time and gives the concentration of fibers per cubic centimeter in less than 3 minutes. The instrument is presently undergoing laboratory and field testing.

2. A miniature gas chromatograph has been greatly improved. Column gas handling valves and detector are etched onto the surface of a silicon wafer. The size of the entire gas chromatograph assembly makes it compatible with the data-handling integrated circuitry so that the entire gas chromatographic instrument can be packaged in a volume not much larger than a pocket calculator. Some of the improvements that have been made on this system include (a) chemical bonding of the polyethylene glycol and Apiezon L lining material to the capillary column surface, (b) development of a thermistor detector compatible with the column size and volume, and (c) development of miniature solenoid valves with nickel parylene membranes for carrier gas and sample gas handling. Sensitivity of previous versions of this GC at room temperature with a 1-microliter-per-second carrier gas-flow rate and a sample volume of about 25 nanoliters has been about 50 parts per million with good separation of peaks.

3. Work has begun on developing a portable microwave spectrometric analyzer. No significant progress has been made yet.

4. Design criteria for an automated, personal-sample fiber counter have been received and evaluated. This instrument will be based on light-scattering principles and is intended to complement the fibrous aerosol monitor mentioned above. It will be capable of counting fibers of asbestos and fibrous glass that have been collected on filters. This obviates the need for the tedious human counting presently required by the regulations.

5. Commercially available personal-sampling devices for cold environments have been evaluated for their performance at temperatures down to -50°C. Various aspects of low temperature use have been considered, such as battery type, lubricant properties, and physical damage. The results thus far indicate that the primary limitation in all the pumps is the battery.

6. Work is currently underway to develop a specific personal-sampling and analytical method for hydrogen sulfide, H_2S, using a solid sorbent.

IMPROVEMENT OF RADIOLOGICAL ASSESSMENT

A study being conducted by TVA, entitled "Development and Evaluation of Improved Radiological Assessment Capabilities," is designed to improve radiological surveillance procedures regarding both sampling and radiochemical analyses of samples. This project is to develop guideline information for the nuclear power industry and to evaluate and refine the models used to predict the radiological impact of releases to the atmosphere from nuclear power plants. The primary objective of the project is to develop an optimum radiological monitoring program. Studies leading to the attainment of this objective have been divided into three major subareas:

1. Development of a model intraorganization quality assurance program for radiological surveillance which will include all TVA environmental and nuclear plant laboratories.

2. Improvement of radiological monitoring techniques with emphasis on gamma spectroscopy methodologies, which are among the most frequently employed analytical tools.

3. Evaluation of presently used environmental radiological surveillance programs. The end product will be a surveillance program capable of meeting required analytical sensitivities and providing adequate assessment information in a cost-effective manner.

A quality assurance program is being developed to assist in demonstrating the accuracy and reliability of output empirical data and to serve as a model for the nuclear industry. It is envisioned that a manual entitled "Handbook for Analytical Quality Control in Radiological Laboratories for TVA Laboratories" will be prepared during this fiscal year and distributed nationwide.

Another report forthcoming from this project will result from the studies of gamma spectroscopy methodologies. Interested organizations will have documented information regarding the resolution of complex gamma spectra and the assignment of lower levels of detection.

To supplement the ongoing work, additional studies should be performed in two areas.

1. Environmental radiological surveillance programs. Field testing of surveillance programs proposed in the ongoing study and evaluation of exposure pathways not considered in detail in the present study should be conducted to ensure proper measurement of environmental impact.

2. Analytical model refinement. Additional work will be necessary regarding the collection of specific radionuclides data around large nuclear facilities.

WATER MEASUREMENT METHODS R&D

The EPA supervises a contract to determine the composition of effluents from coal and oil shale gasification projects. More specifically, the objective of this project is to identify and measure chemical constituents in liquid and solid waste from several energy-related industries. Coal conversion and oil shale processes are the first being studied. To avoid or minimize unnecessary duplication, all pertinent scientific and governmental literature in this area has been reviewed. The investigators have identified information gaps, sampled effluents at appropriate energy projects presently in operation, and performed chemical analyses for chemical elements and volatile organic compounds. This report covers the six types of energy activities and produces tables of all elements and all organic compounds identified in the reports reviewed; for example, 41 chemical elements and 61 organic compounds were found in effluents from coal conversion and oil shale processing. This report also covers the methods for elemental and organic analyses.

Forty-five samples have been analyzed from *in situ* coal gasification at Hannah and Gillette, Wyoming; from a low Btu coal gasification plant at Morgantown, West Virginia; and from an *in situ* oil shale gasification project at DeBeque, Colorado, and Laramie, Wyoming. Examples of reported data illustrate the complexity of some of the samples. More than 74 elements and 200 organic compounds were reported for some samples. These analyses provide specific information that was not previously available for these energy processes.

Another EPA contract recently awarded will provide analogous information about effluents from several energy activities, including coal gasification and liquefication, oil shale processing, coal mining, copper, and coal-fired power plant operations.

BIOMEDICAL AND ENVIRONMENTAL R&D

The objective of ERDA's Division of Biomedical and Environmental Research program is to provide information on potentially troublesome effluents or emissions, information that would be useful in guiding control technology considerations and is needed to develop a comprehensive assessment of environmental and health effects. The specific projects within this program are as follows.

1. Argonne National Laboratory is developing methods for chemical characterization and analysis of airborne particulate material as a function of particulate size and time. This technique is based on infrared spectroscopic analysis of particulate samples. Samples are collected with a Lundgren impactor. The extract of these samples is then analyzed using infrared spectroscopy. During August and September 1975 a field study comparing the Lundgren impactors and the EPA sampling was conducted in the St. Louis region. As expected, sulfates were found in the fine fraction. Overall good agreement between the two methods was found.

2. Brookhaven National Laboratory is conducting a project to determine the primary emissions of sulfate species from various types of fossil-fueled combustion sources and to relate the magnitude of these emissions to variables affecting the combustion and emission control processes. This study also includes collection and analysis of sulfuric acid.

3. Lawrence Berkeley Laboratory is conducting a project to develop an elemental sulfur monitor. The first prototype of this sulfur monitor is in the final stages of construction and should be available for field testing by the time of the Symposium. Another Lawrence Berkeley project is to develop a beta particle attenuation method for large-scale measurement of total particulate mass of samples collected on membrane filter.

SPECIFIC PROJECTS

4. A Lawrence Livermore Laboratory project is to determine a satisfactory method for extending the sensitivity of the microwave ammonia monitor by preconcentration. The objective is to select a preconcentration method so that ammonia can be measured quantitatively down to 1 part per billion by a field-usable instrument.

5. Los Alamos Scientific Laboratory is evaluating the present EPA particulate-sampling method (Method 5) and developing improved methods for extracting particulate samples from stacks. Over the last 18 months, this project has been evaluating glass-fiber sampling filters operated at 120°C and 10.3 cm/s air velocity. So far, efficiency for such filters has exceeded 99.9 percent for particle sizes above 1 μm and approximately 99.6 percent for smaller particles.

6. Oak Ridge National Laboratory is developing instrumentation and methods for characterizing aqueous effluents from oil shale, oil refining, and geothermal sources. One feature of this research is to limit the application of analytical techniques presently available for routine analysis. These researchers are not only using instrumentation methods but are also developing bioassay techniques and incorporating them into the characterization scheme.

7. Lovelace Biomedical and Environmental Research Institute is improving the methods available for chemical and physical characterization of aerosols from processes utilizing fossil fuels, particularly coal. Methods for identification and quantification of potential toxic organic emissions are being developed, as are *in vitro* methods to predict the solubility of particles in the lung following inhalation. Reliable aerosol impactors have been developed for laboratory use.

8. An Ames Laboratory project is developing the basic sciences, the investigative methods, and the hardware so that the demanding analytical requirements for characterization and quantification of heavy-weight organic pollutants and effluents from oil shale and oil refining operations can be met in a viable, practicable manner. In addition, this project is developing methods in hardware so that trace element impurities in geothermal effluents in brines can be determined quantitatively, simultaneously, and with adequate sensitivity.

STANDARD REFERENCE MATERIALS–WATER POLLUTION

The National Bureau of Standards is developing measurement methods and standard reference materials for monitoring water pollution associated with energy production and use. Three areas are covered in its program.

First is the energy-related water-pollution analysis instrumentation, which is coordinated with the EPA Environmental Research Laboratory at Athens, Georgia. Projects currently underway in this area deal primarily with the measurement of organic species and of toxic elements. This involves the coupling of electrochemical detection to liquid chromatography.

Second is the development of standard reference materials for monitoring water pollution resulting from energy production and use. During the first year of this program, workshops were held to determine the standard reference material needs for analysis of the various effluents associated with offshore petroleum, oil shale, coal gasification, power plant operation, mine drainage, etc. Also, a method has been developed which may be used to generate known concentrations of organic compounds. Such concentrations of compounds are coated on glass beads packed in a column for subsequent aqueous elution.

The third area encompasses quality assurance standards for measurement of radiological pollutant. This effort is aimed at providing a series of standards for measurement of radionuclides, with emphasis on alpha emitters. To date, SRMs for PO^{210}, mixed gamma solution, and mancos shale (Ra^{226} and Ra^{228}) have been delivered to EPA.

MEASURING WATER & WATER-RELATED CONSTITUENTS

A U.S. Geological Survey project is primarily in the area of development, testing, and application of methods, techniques, and instruments for measuring water and water-related constituents and characteristics. The four areas of this project are specifically: (1) development of methods for characterizing and monitoring levels of chronic toxicity, (2) development of instrumentation for high-volume analysis of petrochemicals and associated compounds, (3) development of bedload samplers for measuring stream sediments, and (4) development of flumes, weirs, and other devices and techniques for measuring sediment-laden stream flows. A major contribution of this study has been the development of methods permitting elucidation of the role of physicochemical factors on bioavailability of sediment-bound trace metals.

To meet the requirement for the large amount of data, this project is also developing criteria by which laboratory managers can determine the most effective methods and best instruments for analyzing large volumes of samples from petrochemicals and associated compounds.

This project is developing one or more samplers for accurately measuring the discharge of bedload in natural streams. This will be done by testing and calibrating existing samplers to define the operating characteristics and efficiencies in sampling different sizes of sediment under various hydraulic conditions. On the basis of this information, sampler designs will be modified and new bedload samplers will be designed.

Investigations are underway into alternative techniques of measuring stream flow in open channels. Presently, three methods of measuring discharge or velocity are being considered, all of which require little or no contact with the water: (1) fluorometric, (2) photometric or video, and (3) microwave.

ENVIRONMENTAL DATA MEASUREMENT UNCERTAINTIES

The Office of Marine Technology of the National Oceanic and Atmospheric Association (NOAA) has a program for developing appropriate mechanisms to define and control within prescribed limits the measurement uncertainties associated with environmental data. These data quality provisions, when applied to environmental monitoring programs, result in qualified data, that is, data with known error bands and a defined relation to accepted standards. Development of standards is presently underway in the following areas.

1. Development of a laboratory dissolved-oxygen standard is currently in progress.

This standard will substitute for the Winkler method currently used as a reference method for calibration of dissolved-oxygen measurements systems. The standard will operate in a test bath over a range of -2°C to 35°C and from 0 to 40 parts per thousand in salinity. The dissolved-oxygen range will span 0 to 15 parts per million.

2. Development of a dynamic test apparatus for laboratory testing of flow sensors is nearing completion. This apparatus will generate controlled dynamics superimposed on steady flows to determine measurement capabilities of flow sensors in a nonsteady flow environment. The apparatus is being designed and fabricated by the Naval Ship Research and Development Center (NSRDC). The capability to simulate field conditions will provide more realistic definition of sensor characteristics and limitations.

3. Transfer standards are utilized to assess the comparability of results obtained from different laboratories performing similar calibrations. A conductivity/temperature/depth system has been selected as one of the development areas. This system is undergoing laboratory evaluation over a 6-month period to verify its measurement capability. Subsequently the system will be shipped to another laboratory for calibration. The uncertainty goal for this calibration technique is ±0.01 percent of the reading.

SUBTASKS INCOMPLETE

At present none of the subtasks have reached completion; thus statements of success or failure are somewhat premature. For those areas discussed, however, progress to date has been favorable and indications are that the objectives will be met.

ELECTRO-OPTICAL TECHNIQUE

A joint EPA/NASA project is being carried out to develop and apply an advanced electro-optical technique to the measurement and characterization of power plants and other effluent sources. There are five tasks in this project.

1. The first task is to evaluate Raman lidar for remote measurement of the concentration of SO_2 at power plant stack exits. Raman optical lidar systems have been developed at NASA and successfully applied in the measurement of water vapor and density profiles in the earth's atmosphere. More recently, the Raman technique has been used with some success to detect SO_2 in power plant stack plumes.

An existing system at NASA Langley has been modified and improved and is now being calibrated. Preliminary results show that at a range of 500 meters and night background light levels, the Raman lidar system can measure SO_2 concentrations of 1,000 parts per million within 10 percent.

2. Task 2 is to apply aerosol scattering lidar techniques to the study of plume dispersion under various atmospheric conditions. This involves modifying an existing lidar technique developed by NASA for dispersion studies of plumes from rocket launches. The task was originally scheduled for completion in 1976; however, no funds

were allocated during the second year because of severe budget constraints. Funds have been allocated during the third year and work will be resumed subject to approval by the EPA Project Officer.

3. Task 3 is to develop and apply the tunable infrared (IR) differential absorption lidar technique to remote measurement of molecular plume effluents. It employs the principle of differential absorption technique where sequential measurements are made first on an absorption line and then at a nearby wavelength off the absorption line, thereby providing information on range-resolved data for particular gases. The contract has been let for tunable IR laser, which is to be delivered in late 1977. This task is scheduled for completion in late calendar year 1978.

4. Task 4 is to develop the use of a laser heterodyne detector to increase the sensitivity of long-path continuous-wave absorption measurements using diffuse deflectors. The infrared heterodyne radiometer is scheduled for completion in December 1977, at which time a technical report on evaluation of this system will be furnished to EPA.

5. Task 5 is to develop and deliver to EPA an improved *in situ* HC1 chemiluminescent monitor evaluated at concentrations as low as 5 ppb of HC1 in ambient and polluted air. The instrument has been evaluated in the laboratory to determine the operational characteristics.

The Wave Propagation Laboratory, NOAA, is investigating lidar techniques for analyzing and tracing particulate pollutants from energy production. Improvement of lidar techniques is required to increase accuracy of identification and measurement of size distribution, shape factors, and concentration. Two steps have been taken to improve remote detection and measuring methods for particular pollutants. The depolarization technique has proven useful in studying plume dispersion in impact assessment programs and in distinguishing plumes from natural background aerosols. Preliminary results on two wavelength techniques have indicated potential for improved identification of particles. Theoretical studies have resulted in improved application of mathematical inversion algorithms to deduce the properties of particles from their electromagnetic signatures. The depolarization technique in impact assessment studies has been successfully employed at Colstrip, Montana. Initial tests of the dual wavelength system for estimating mean particle sizes are encouraging. In the immediate future, field tests will be conducted on the depolarization technique and the two wavelength techniques. Plans are being formulated for the study of differential absorption and inelastic scatter techniques.

LIDAR TECHNIQUES—PARTICULATE POLLUTANTS

The Wave Propagation Laboratory is also carrying out a project entitled "Doppler Lidar for Measurements of Pollutant Transport." Doppler lidar measures the small-scale,

boundary-layer wind field by frequency-analyzing the signal backscattered from aerosols. The purpose of this research program is to develop and test operational techniques for the high-resolution measurement of atmospheric wind, turbulence, and aerosol backscatter aspects of pollutant transport. Results to date include both technique refinement and field measurements, such as wind profiles, to a range of 1 kilometer and a height of 200 meters, velocity spectra of vortices, FM-CW lidar ranging, three-component velocity measurements, and plume backscatter. Planned research includes aerosol profiling, range extension, and more efficient data processing. The research task is 2 years into a 5-year program. Milestones are on schedule.

AIRBORNE ACTIVE REMOTE SENSING

An EPA study is evaluating airborne active remote sensing of pollutants associated with energy production. All of the systems utilize lasers to produce the interrogating signal, and all of the systems operate in a downward mode from airborne platforms.

The first system is a downward-looking lidar which ranges aerosol scattering in the atmosphere below the plane. An operational system has been tested which features a real-time display of lidar return signals.

Ground and flight testing of a prototype earth-reflected differential absorption system for ozone monitoring has been completed and promises great utility in studying long-range oxidant transport problems. A system for monitoring sulfur dioxide is being designed, and a computer simulation model has been created to optimize component-selection-system response and display options.

Laser fluorosensing techniques are being evaluated for use in monitoring the presence or effects of environmental pollutants in water. Concentration of surface water chlorophyll *a* in algae is presently being monitored using the helicopterborne laser fluorosensor. A similar system is also being designed to map and quantify surface water total organic carbons.

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environment II

GEORGE B. MORGAN

B.S., Chemistry, Valdosta State College, GA; M.S., Bioanalytical Chemistry, University of Florida; additional graduate work at New York University. Member of delegation to United Nations Environmental Program Working Group, joint effort by U.S./U.S.S.R. in air pollution monitoring methodology. Was an associate professor of radiological health and later Director, Phelp's Laboratory for Bioenvironmental Engineering Research, University of Florida. Held many key positions in the health and ecological field—U.S. Public Health Service Laboratory, Cincinnati, OH; Chief of Laboratory Services and Director of the Air Quality and Emissions Data Division; Director of Division of Atmospheric Surveillance, National Air Pollution Control Administration and Director of the Quality Assurance Division, EPA. Currently, Director, Environmental Monitoring and Support Laboratory, EPA, Las Vegas, NV.

questions & answers

Mr. Chris Timm
USEPA

Mr. Vernon J. Laverty
Hydronautics Inc.

Mr. David E. Kidd
University of New Mexico

QUESTION: One of the slides showed measurement and organic measurement. Was there a distinction between particulate organics and nonparticulate organics?

RESPONSE: Mr. Andrew E. O'Keeffe (EPA)

We are presently collecting the organics in the vapor phase. It is a matter of convenience. We realize that particulate organics are equally as important, if not more so, but we are still trying to master nonparticulate organics.

QUESTION: I am interested in knowing whether the filters or personal evaluation filters, which were mentioned with regard to asbestos, are available now?

RESPONSE: Dr. Paul Baron (NIOSH)

It is not a filter technique. It is actually a portable monitor that detects light scattering from asbestos fibers and counts them. It is an instrument that will probably be commercially available some time next year. We are presently evaluating it at the moment.

QUESTION: Could you tell us more about the miniaturized GC?

RESPONSE: Dr. Baron

The miniaturized GC represents a contract with the Stanford University Electronics Laboratory. They have built a gas chromatograph by etching the column on a 3-meter column, 20 microns by 200 microns diameter, on a silicon wafer about 2 inch by 2 inch; and they have included on this wafer the valving detector. We think this is an exciting technique and may be a generalized detector for a number of other processes. At present it is simply a feasibility study, but they have developed the instruments further.

QUESTION:

You mentioned the laser fluoro-sensing technique, relating it to the concentration of surface water, chlorophyll A, and algae.

Since chlorophyll A is a biomass measurement, do you get a good relationship and good graph in regard to sensing the amount of chlorophyll A present, hence the biomass of algae?

RESPONSE: Mr. John A. Eckert (EPA)

Our tests using the helicopter are made on Lake Mead and up a stream leading into Lake Mead with an increasing gradient in chlorophyll A concentration; the correlation is quite good.

QUESTION:

Have you tried Lake Powell?

RESPONSE: Mr. Eckert

No. We have only made our tests on Lake Mead, which has the unique feature of having almost no chlorophyll in the center of the lake and a rather extreme gradient up the Las Vegas wash.

Edward Lee Tilton III
Dr. David N. McNelis
Frederick A. Kilpatrick

technical discussion

AIR AND WATER QUALITY DATA INTEGRATION IN THE WESTERN ENERGY RESOURCE DEVELOPMENT AREA

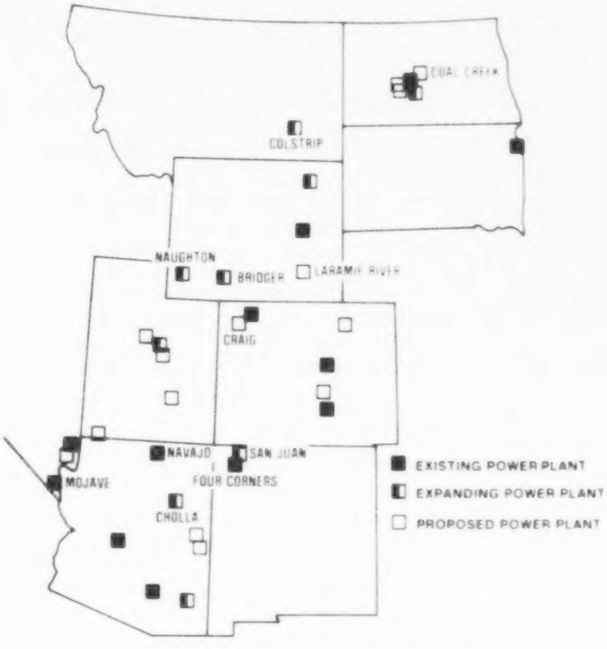
David N. McNelis
Environmental Monitoring and Support Laboratory
U.S. Environmental Protection Agency
Las Vegas, Nevada

Concern about environmental impact of the energy development activities underway and under consideration in the western United States is apparent in both the executive and legislative branches of our Government. Policy statements, legislative proposals and research mandates are appearing with increasing frequency and most relate either directly or indirectly to the resources existing in the Western Energy Resource Development Area (WERDA). Historically, the West has been an area with a relatively low population density and correspondingly low industrial development. Because of these factors, it contains several so-called pristine areas generally not impacted by anthropogenic activities. A general deterioration, however, in the air quality over the whole region, particularly with respect to visibility, over the last several years is widely acknowledged and concern over any additional degradation is mounting. The magnitude of the problem as viewed by the Government is demonstrated by the proposed legislation dealing with the prevention of significant deterioration and the designation of Federal lands (national and international parks, national wilderness and primitive areas, and national preserves and memorial areas) as areas where essentially no deterioration is permitted.

Also of concern in the West is the potential impact on water quality and supply. Water is already in short supply in the semiarid West. The accelerated energy developments in these areas are in direct competition with other uses for the limited available water resources. The extraction of raw materials, fuel refinement, transport and utilization, and the accompanying demographic changes will place additional demands on available water. The water quality stands to be degraded as both the consumptive and non-consumptive use increases and as major hydrographic changes are made as a result of diversion of water to use sites.

Abundant in the West are vast resources of low-sulfur coal, uranium, oil shale and geotherms. Coal, once the major resource consumed for conversion into electrical power, now supplies less than 20 percent of our current energy demands. The size and availability of the western coal reserves dictate that the accelerated use of coal can be reevaluated. Coal is also being considered for conversion into clean-burning synthetic fuels, and demonstration projects are already under development. The Green River Formation of Utah, Colorado, and Wyoming contains approximately 80 percent of the identified oil-shale resources in the United States. The West also contains the majority of this country's uranium deposits.

Most of the coal produced during the next two decades will be utilized in steam boilers for the production of electrical power. Several such facilities exist in the West, some of which will be expanded. In addition, several new plants are scheduled for construction. Figure 1 shows the status of these facilities on a map encompassing the WERDA.



(NAMED PLANTS— CAPACITY GREATER THAN 1000 MW)

Figure 1. Fossil fueled power plants greater than 300MW.

The continued and accelerated development of the various energy resources in the West potentially will impact the environmental quality of this region in other ways as well. Air and water quality degradation from extractive processes and refining and energy conversion operations needs to be predicted, assessed, and included in the planning of energy resource development and environmental quality.

Long-term measurements of air and water quality parameters are essential to develop the accurate data base to serve as a foundation for the planning processes. Meso- and macro-scale data regarding pollutant concentrations and the alterations in concentration, pollutant mix and related parameters resulting from development activities are critical to the responsible study and decision process.

This paper describes the initial results of

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a major interagency program directed at integrating air and water quality monitoring data in the WERDA. Participating with the U.S. Environmental Protection Agency are elements of the National Oceanic and Atmospheric Administration and the U.S. Geological Survey. Several other agencies of the Federal and State governments are cooperating in the study.

The map in Figure 2 shows the particulate monitoring network used in the WERDA which consists of over 400 stations. Depending on the analysis desired, these stations are stratified according to the surveillance classification of the sampling site, i.e., population, source or background. Less than half of these stations are located in rural areas and related to the last category of background monitoring sites. These are the stations which are most useful to a regional assessment of ambient air quality and associated energy impacts. The surveillance classification of the network is being reviewed to assure uniform application of the stratification criteria. A high-volume air sampler is used at nearly all of the sites. The filter is weighed and the mass of the total suspended particulate (tsp) concentration is determined. Trace element, sulfate, nitrate, sulfur dioxide and nitrogen dioxide analyses, however, are performed on samples from less than 40 percent of the monitoring stations, while ozone, carbon monoxide and hydrocarbons are monitored at only a few sites.

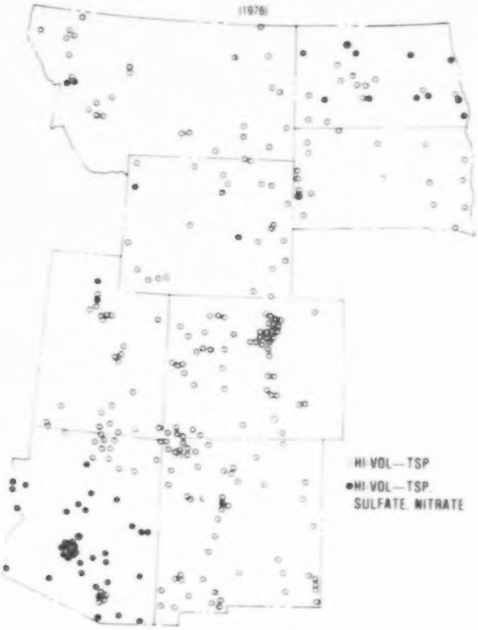

Figure 2. Particulate sampling in WERDA.

Ideally, for this study, the parameters being monitored should be related to a characteristic of the energy development activities in the geographic region under investigation. Because of the emphasis on coal extraction and combustion for energy production, sulfate analyses become of increased significance. Also, the measurement of total-suspended particulates, while of interest, is perhaps not the most sensitive aerosol analysis related to fossil fuel combustion. Most of the mass collected on a filter is associated with a size fraction produced by comminution processes, while the fine particles produced as a result of gas-phase reactions and condensation and coagulation phenomena in a power plant stack and plume account for little total mass. Finally, visibility, which is a function of the fine particulate loading of the atmosphere, is not being measured in any network. Only recently the first attempts at monitoring visibility and visibility-related parameters are being conducted at a few selected sites.

Under the interagency energy program, significant progress has been made to identify and expand a network of air quality monitoring stations with which an environmental baseline can be established and the contribution of energy development and related activities assessed. In addition, the analyses are being extended or otherwise modified to make them more sensitive to identify and quantify energy-related impacts

A regional sulfate-nitrate network has been established which incorporates the existing State-operated sulfate monitoring stations (generally one or two stations per State) and added 77 sites throughout the eight-State region. Almost half of these were added via grants through the EPA Region VIII Office to the States and the balance via an existing contract with the Ute Research Laboratory. The Ute network of 29 sites is now included in the regional network. Filters from Utah and Wyoming are also being analyzed at that Laboratory. The regional network became fully operational in May 1977. Figure 2 shows the distribution of the sulfate-nitrate monitoring stations prior to 1977 and Figure 3 shows the distribution of the recently added sites which were integrated into the network.

The network of the Ute Research Laboratory is also being used to collect samples for trace element analyses (Fe, Cd, Cr, Co, Pb, Cu, Mn, Ni and Mo) and total-suspended particulate determinations. The network is located in the Four Corners area of Colorado, Utah, New Mexico and Arizona and has stations strategically placed downwind of several major existing and proposed power plants and mining sites. Multi-stage cascade impactors are being evaluated at a few of the stations to determine the utility of detailed size and elemental analyses as a means of developing signatures for specific energy production/development facilities. The size fractions selected should distinguish the fine particulates, which degrade visibility and are respirable, physiologically significant, and produced in, or result from, combustion processes, from the relatively coarse particulates of natural origin or fugitive dust.

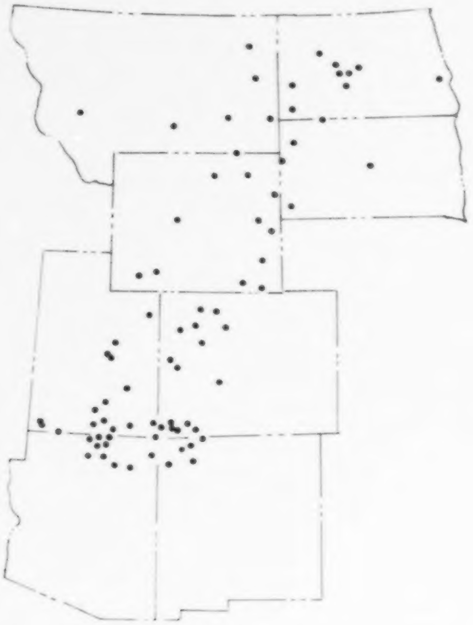

Figure 3. Sulfate - nitrate monitoring sites added during 1977.

A major advancement allowing air-quality monitoring data to be used for regional-scale assessments has been made through the initiation of a quality assurance program. Seventeen participating laboratories, including Federal, State and private, are involved in a uniformly applied audit and cross-check program that permits data from all of the long-term monitoring stations in the WERDA to be entered into SAROAD, the national air quality data base, with assurance of their relatability. To implement this program, each of the laboratories and many of the field sites were visited and the analytical technology reviewed. A written evaluation was prepared for each facility and follow-up assistance is being provided. Quarterly performance audits for mass determinations, flow measurements and NO_2, SO_2, CO and non-methane hydrocarbons have also been initiated. This phase of the program has only recently commenced for the final phase, i.e., that of providing consulting services and dynamic calibration for continuous monitors, will be provided as necessary.

Visibility deterioration, probably the first observable impact on air quality from energy development and related activities, is not being quantitavely measured in the WERDA. However, there are a few initiatives in this region where prototype instrumentation and technology are being evaluated. Visibility is defined with respect to a measure of contrast which changes as a function of light-source position and the position of object and observer with respect to each other. It is not a direct measure of the particulate loading of the atmosphere and, therefore, is not the light "extinction potential" of an airspace. A prototype monitoring station is now being established near a national park in Utah to evaluate and develop visibility and visibility-related measurement instrumentation and to develop correlations among the data of the various methods. Meteorological data will be analyzed and particulate chemical and physical characterizations will be conducted simultaneously to further correlate these data and, if possible, to identify the sources of the pollutants.

A network of visibility monitoring stations is also proposed which will be operated at national parks in cooperation with the National Park Service. Tentative sites are shown in Figure 4. Data from this network will serve to provide a baseline for visibility over a geographical area of great national significance for its scenic vistas.

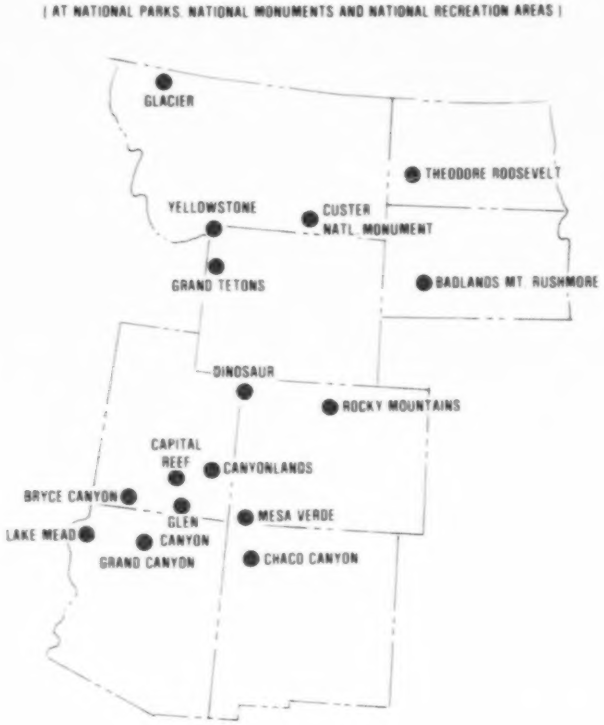

Figure 4. Proposed visibility monitoring sites.

Finally, two other projects are being conducted which will provide data directly related to the regional aspects of the energy program. Wide-area monitoring is being conducted using an air-quality monitoring aircraft. This aircraft system is being subjected to the same quality assurance program previously described and is being used to assess the regional impacts and long-range transport of energy-related pollutants. Regional scale models have also been reviewed and selected for their application in predicting impacts of present and proposed power plant developments in the WERDA.

Energy resource development scenario information and data regarding exisiting facilities, existing and anticipated pollutant specification, locations and concentrations were also used to identify a network of water quality monitoring stations in the WERDA. Over 200 currently active, data-rich (25 or more parameters monitored for a period of at least 2 years) surface-water monitoring stations were selected for this network. Other stations and those of special studies are incorporated when and as necessary to fill specific data gaps. Data gathered are coded into STORET, EPA's water quality data base, and are retrieved for statistical analyses, listings, and summarizations.

In contrast to the air-quality data integration effort where a paucity of relevant data and parametric coverage by monitoring stations exists, there are many water-quality monitoring stations, sampling several parameters of interest and dispersed over an area to provide a synoptic perspective to the status of water quality. The problem is associated with the relatively large amount of data to be reviewed and assessed. This problem is compounded by the ephemeral nature of the Western water resources. Many tributary streams to the major waterways are seasonally intermittent.

The publication of the Western Energy/Environment Monitoring Atlas with its Air, Water and Remote Monitoring Appendices presents the initial findings of this multi-media, interagency program. It presents the status of environmental quality and monitoring networks, along with an assessment of environmental impacts from energy developments and related activities. These findings are usable by planners at the local, regional and national levels in providing for the environmentally acceptable development of western energy resources.

WATER MONITORING IN ENERGY DEVELOPING AREAS

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Geological Survey
U.S. Department of Interior
Reston, Virginia

Presently the Water Resources Division of the U.S. Geological Survey operates a network of 6200 water quality monitoring stations nationwide. Of these, 590 are in the Rocky Mountain and Northern Great Plains States of Colorado, Montana, North Dakota, New Mexico, Utah and Wyoming. Of these 73 are funded partially via EPA funds. Funding also comes from the USGS, BLM, and State Coop programs.

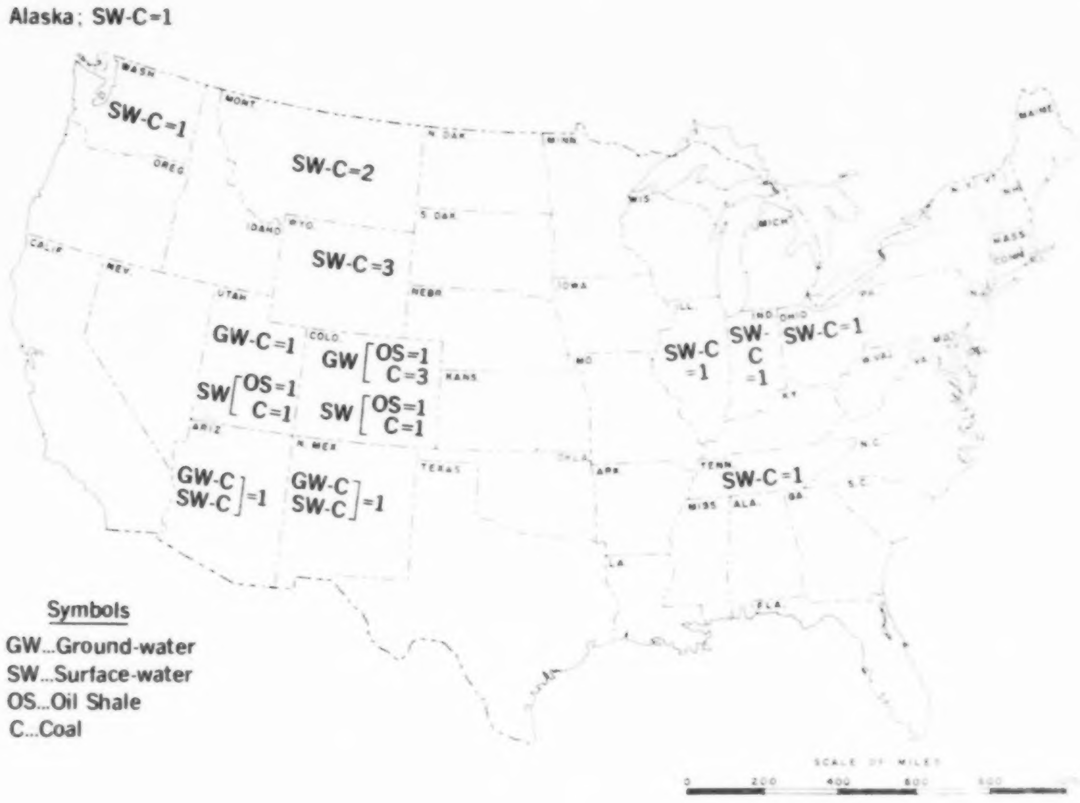
Figure 1 illustrates the type, number, and locations of projects being supported by EPA. For most of these projects EPA funds provide for the collection and analysis of a broader suite of water quality parameters than that normally obtained by the USGS. Many represent the routine operation of water monitoring stations to establish baseline water quality, sediment, and flow conditions against which future assessments of impacts can be made. Other studies are not only baseline monitoring projects, but feature interpretative analyses of the effects of mining and reclamation. This report gives results obtained by 3 of the 22 projects involved in the Interagency Energy/Environment R&D Program with the USGS as described in this paper.

QUALITY OF WATER MONITORING IN THE CHACO RIVER BASIN, NEW MEXICO

Introduction

The demand for energy has stimulated the development of energy resources in northeastern New Mexico (Figure 2). The existing Four Corner's powerplant and its associated Navajo Coal Mine as well as the newer San Juan powerplant are planning for expansion. Through its subsidiary, Western Coal Co., the San Juan powerplant may strip-mine coal from areas south of its current powerplant-mining complex. The proposed Western Gasification Company's (WESCO) gasification plant and the proposed El Paso Company's gasification plant will convert coals that are mined adjacent to the plants into pipeline fuel gas.

Peabody Coal Company's Star Lake Mine will begin strip-mining coal in 1978 and ship it via the Santa Fe Railroad to the Coronado powerplant


Alaska; SW-C=1
WASH
SW-C=1
OREG
MONT
SW-C=2
N DAK
MINN
S DAK
IDAHO
WYO
SW-C=3
CALIF
NEV
UTAH
NEBR
IOWA
GW-C=1
COLO
GW [OS=1 C=3]
SW [OS=1 C=1]
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ARIZ
N MEX
TEXAS
OKLA
ARK
GW-C SW-C]=1
GW-C SW-C]=1
WIS
MICH
ILL
IND
OHIO
SW-C =1
SW-C =1
SW-C=1
KY
W VA
VA
PA
N Y
VT
N H
MAINE
MASS
CONN
N J
MD
TENN
SW-C=1
N C
S C
MISS
ALA
GA
LA
FLA
Symbols
GW...Ground-water
SW...Surface-water
OS...Oil Shale
C...Coal
SCALE OF MILES
0
200
400
600
800
1000

Figure 1. Type and number of energy R&D projects being undertaken by the USGS for the EPA.

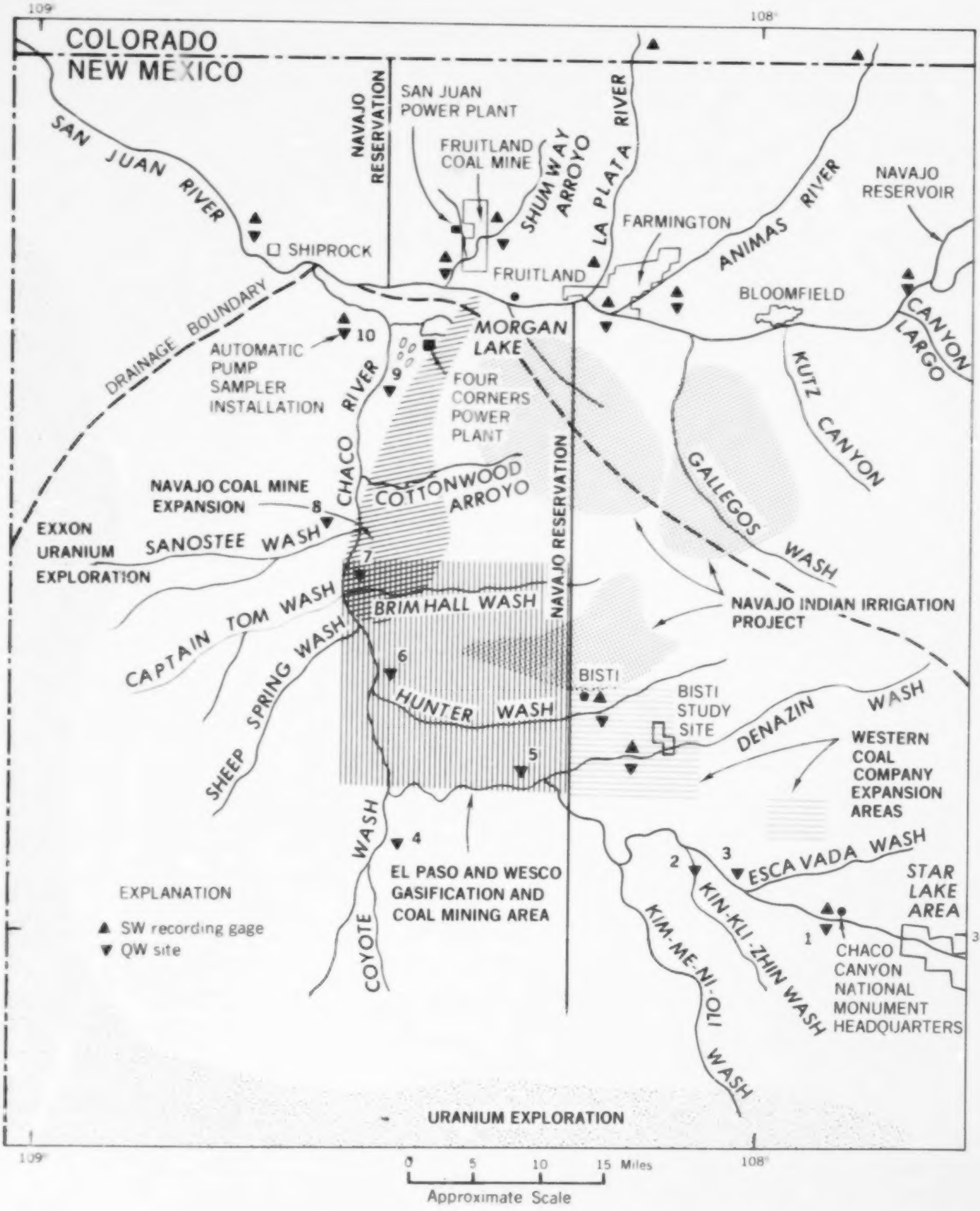
109°
108°
37°
36°
COLORADO
NEW MEXICO
SAN JUAN RIVER
SHIPROCK
NAVAJO RESERVATION
SAN JUAN POWER PLANT
FRUITLAND COAL MINE
SHUMWAY ARROYO
LA PLATA RIVER
FARMINGTON
ANIMAS RIVER
NAVAJO RESERVOIR
FRUITLAND
BLOOMFIELD
CANYON LARGO
DRAINAGE BOUNDARY
MORGAN LAKE
AUTOMATIC PUMP SAMPLER INSTALLATION
10
9
FOUR CORNERS POWER PLANT
KUTZ CANYON
CHACO RIVER
GALLEGOS WASH
NAVAJO COAL MINE EXPANSION
8
COTTONWOOD ARROYO
EXXON URANIUM EXPLORATION
SANOSTEE WASH
7
NAVAJO RESERVATION
CAPTAIN TOM WASH
BRIMHALL WASH
NAVAJO INDIAN IRRIGATION PROJECT
SHEEP SPRING WASH
6
BISTI
HUNTER WASH
BISTI STUDY SITE
DENAZIN WASH
WESTERN COAL COMPANY EXPANSION AREAS
5
4
COYOTE WASH
EL PASO AND WESCO GASIFICATION AND COAL MINING AREA
2
3
ESCAVADA WASH
STAR LAKE AREA
KIN-KLI-ZHIN WASH
KIM-ME-NI-OLI WASH
1
CHACO CANYON NATIONAL MONUMENT HEADQUARTERS
EXPLANATION
▲ SW recording gage
▼ QW site
URANIUM EXPLORATION
0 5 10 15 Miles
Approximate Scale

Figure 2.

Map of Chaco River area.

in eastern Arizona. El Paso Natural Gas Co. is intensifying their petroleum drilling and production program in this area. Exxon Corp. has negotiated an agreement with the Navajo Tribe to explore for uranium on the Navajo Reservation. The western and southern parts of the Chaco River basin are potential uranium mining areas.

Compounding these energy developments will be the Federally-funded NIIP (Navajo Indian Irrigation Project) which is to provide irrigation for over 110,000 acres of Indian land east of the energy areas.

Discussion

Within the above developments the major water users are deriving or will derive their water supplies from the San Juan River system. As much as 500,000 acre-feet of the annual average total of 1,600,000 acre-feet as measured on the San Juan River at Shiprock may be diverted for these projects. Smaller supplies will be developed and pumped locally from deep underground sources. Unconsumed portions of these supplies will return to the San Juan River via the Chaco River system.

The Chaco River is a tributary to the San Juan River, and all or parts of the above developments lie within the Chaco River drainage basin. The Chaco River and its tributaries are arroyos except for a small reach of the Chaco River near its mouth which recently has developed a small perennial flow downstream from the Four Corner's powerplant. Runoffs in the Chaco River system occur sporadically during summer and early autumn as the result of localized, short duration, high intensity rainstorms. The arroyos are usually dry the remainder of the year. The Chaco River follows the strippable coal deposits in the Kirtland Shale-Fruitland Formation along the western and southern margins of the San Juan structural basin. Many of the arroyos overlie the strippable coal. Potential uranium development areas are within the western and southern parts of the Chaco River basin. Uranium mine drainage may be pumped into the Chaco River system. A portion of the NIIP area is in the eastern part of the Chaco basin. Irrigation drainage may flow to the Chaco River, but only after traversing the strippable coal areas. While the Chaco River system may presently be dry on the durface, a component of flow may be moving towards the San Juan River underground within the alluvial bed of the arroyo trough.

Available data on the quantity and quality of the water resource in the Chaco River basin are very sparse. The impact of the energy development, particularly on water quality, in the Chaco basin and ultimately downstream in the San Juan River and Colorado River must be assessed. The U.S. Geological Survey's Water Resources Division is establishing a monitoring network for collecting hydrologic information in the energy development areas of the Chaco River basin which will be complementary and supplementary to current investigations with BLM and the State of New Mexico. Figure 2 indicates the scale of development anticipated in northwest New Mexico and the water monitoring stations in operation in the Chaco River basin. Table 1 shows representative water quality data at 3 stations for 3 conditions of flow. Table 2 shows representative quality data for water from the shallow ground water wells in the alluvium of the lower Chaco River. This data represents baseline or present water quality conditions of both surface- and ground-water resources which will help determine the effects of proposed energy developments in the area.

TABLE 1. SELECTED REPRESENTATIVE WATER QUALITY VALUES FOUND IN THE CHACO RIVER BASIN IN NORTHWESTERN NEW MEXICO'S ENERGY DEVELOPMENT AREA. MAY 1976 - APRIL 1977

Surface Water Sites

PARAMETER	SITE NO.		
	1	7	10
	SNOW MELT	SUMMER STORM	"BASE" FLOW
DISCHARGE,CFS	5.0	100-1500	20
SPECIFIC CONDUCTANCE, μMHO/CM	270	900	2700
pH, STANDARD UNITS	7.8	7.1	8.3
WATER TEMPERATURE, °C	3.5	---	3.0
* Following Concentrations in MG/L			
SILICA (SiO_2)	5.4	19	11
CALCIUM (Ca)	9.8	69	290
MAGNESIUM (Mg)	1.4	5.8	67
SODIUM (Na)	47	170	270
POTASSIUM (K)	2.3	5.9	8.0
BICARBONATE (HCO_3)	110	403	108
CARBONATE (CO_3)	0	0	0
SULFATE (SO_4)	30	200	1200
CHLORIDE (Cl)	2.9	19	140
FLUORIDE (F)	0.5	0.8	7.4
NITRITE & NITRATE (N)	1.8	0.09	4.1
ORTHOPHOSPHATE (P)	0.05	0.14	0.02
DISSOLVED SOLIDS, SUM	162	689	2280
TOTAL HARDNESS ($CaCO_3$)	30	200	1100
NON-CARBONATE HARDNESS ($CaCO_3$)	0	0	950
CARBON, TOTAL ORGANIC (C)	22	262	6.4
NITROGEN, TOTAL (N)	2.0	---	4.4
PHOSPHOROUS, TOTAL (P)	0.83	---	0.43
NITROGEN, TOTAL AMMONIA (N)	0.06	---	0.08
SUSPENDED SEDIMENT CONCENTRATION	3700	53,600 to 86,800	500
PARTICLE SIZE IN SILT-CLAY RANGE %	1.00	80 to 90	100
** Following Concentrations in μG/L			
ALUMINUM, DISSOLVED	---	---	---
ALUMINUM, TOTAL	---	540,000	---
ARSENIC, DISSOLVED	1	---	3
ARSENIC, TOTAL	34	500	9
BARIUM, DISSOLVED	---	---	---
BARIUM, TOTAL	---	9300	---
BORON, DISSOLVED	40	80	7600
BORON, TOTAL	250	250	7600
CADMIUM, DISSOLVED	0	---	0
CADMIUM, TOTAL	<10	20	10
CHROMIUM, DISSOLVED	0	---	0
CHROMIUM, TOTAL	30	250	20
COBALT, DISSOLVED	1	---	0
COBALT, TOTAL	<50	---	<50
COPPER, DISSOLVED	6	---	2
COPPER, TOTAL	70	---	30
IRON, DISSOLVED	60	30	230
IRON, TOTAL	72000	420,000	21000
LEAD, DISSOLVED	2	---	2
LEAD, TOTAL	100	800	<100
LITHIUM, DISSOLVED	0	30	---
LITHIUM, TOTAL	70	520	160
MANGANESE, DISSOLVED	10	---	20
MANGANESE, TOTAL	730	23000	260
MECURY, DISSOLVED	0.0	---	0.0
MECURY, TOTAL	0.2	2.7	0.2
SELENIUM, DISSOLVED	1	0	30
SELENIUM, TOTAL	2	0	30
STRONTIUM, DISSOLVED	130	---	---
STRONTIUM, TOTAL	530	5900	2000
VANADIUM, DISSOLVED	8.0	0.4	0.4
ZINC, DISSOLVED	0	---	40
ZINC, TOTAL	300	---	80
MOLYBDENUM, TOTAL		20	0

TABLE 2. SELECTED REPRESENTATIVE WATER QUALITY VALUES FOUND IN THE SHALLOW GROUNDWATER OF THE CHACO RIVER BASIN MAY 1976 - APRIL 1977

PARAMETER		CONC.
ALK, TOT (AS CACO3)	MG/L	294
ARSENIC TOTAL	μG/L	2
BICARBONATE	MG/L	359
BORON DISSOLVED	μG/L	70
CALCIUM DISS	MG/L	370
CARBONATE	MG/L	0
CHLORIDE DISS	MG/L	17
DEPTH BELOW LSD (FT)		3.0
DEPTH OF WELL IN FT.		5.0
FLUORIDE DISS	MG/L	0.6
HARDNESS NONCARB	MG/L	800
HARDNESS TOTAL	MG/L	1100
IRON DISSOLVED	μG/L	60
MAGNESIUM DISS	MG/L	41
MERCURY TOTAL	μG/L	0.1
NO2+NO3 AS N DISS	MG/L	1.0
PH FIELD		7.3
PHOS ORTHO DIS AS P	MG/L	0.02
PHOSPHATE DIS ORTHO	MG/L	0.06
POTASSIUM DISS	MG/L	11
RESIDUE DIS CALC SUM	MG/L	2510
RESIDUE DIS TON/AFT		3.41
SAR		5.0
SELENIUM TOTAL	μG/L	3
SILICA DISSOLVED	MG/L	12
SODIUM DISS	MG/L	380
SODIUM PERCENT		43
SP. CONDUCTANCE FLD		3200
SP. CONDUCTANCE LAB		3170
SULFATE DISS	MG/L	1500
WATER TEMP (DEG C)		7.5

As can be seen from the base flow and well data, very hard calcium-sulfate water exists naturally. Furthermore, even very low flows as well as storm runoff produces high suspended sediment loads reflected in the high aluminum, iron, and other metal concentrations.

ACID MINE DRAINAGE IN SOUTHEASTERN OHIO

Introduction

The eastern third of Ohio contains extensive bituminous coal deposits which have been mined since the early 1800's. These coals are found in strata of the Pennsylvanian and Permian systems. The strata represent a fluvial-deltaic depositional environment and are characterized by alternating sandstones, shales, mudstones, coals, and marine, brackish, and freshwater limestones. Mining has ranged from small, hand-dug workings to underground and surface operations encompassing several square miles and utilizing mammoth equipment. All of these operations have had some degree of impact upon the environment. The objective of this project is to study in two phases the impact of coal mining on the water quality in eastern Ohio.

Discussion

The first phase of the study, a reconnaissance of water quality at 162 sites, was conducted to document the severity of the acid mine drainage problem and to pinpoint affected streams. Results of the reconnaissance phase are summarized in Table 3.

TABLE 3.

TYPES OF MINING VS SELECTED WATER QUALITY PARAMETERS (119 SAMPLING SITES REPRESENTED)

Conditions Upstream from Sampling Site	Greater than pH 6.5	Less than pH 6.5	SO_4 less than 250 mg/l	SO_4 greater than 250 mg/l	Specific conductance less than 650	Specific conductance greater than 650
Abandoned Underground	6	32	11	27	11	27
Abandoned Strip	1	6	0	7	0	7
Working Underground	2	3	1	4	0	5
Working Strip	8	1	2	7	1	8
Reclaimed Strip	26	0	6	20	6	20
No Evident Mining	28	0	23	5	23	5
Abandoned Dumps, Tailings Piles, Etc.	1	5	0	6	0	6

The second phase of the investigation involves a more comprehensive water quality sampling program in the following basins:

	Location	Drainage Area-Sq. Mi.	Category
A.	Huff Run: Tuscarawas-Carroll Counties, flows west towards Mineral city	13.95	Abandoned Strip Mine
B.	South Fork, Short Creek: Harrison County, flows east toward Adena	14.42	Reclaimed Strip Mine
C.	Spencer Creek: Belmont County, flows northeast toward Morristown	13.6	Reclaimed Strip Mine within the last year or still active
D.	Snow Fork: Hocking-Athens Counties flows so. through Murray City	27.29	Abandoned Underground Mine

Location of the individual watersheds is shown in figure 3. Phase two objectives include determination of source and chemical quality of water in each tributary, evaluation of the influence of tributary conditions on mainstream water quality, and determination of material loading of streams and tributaries. Results of the phase two sampling program are illustrated in Figures 4 and 5 for two of the basins. The contrast in the data for an area of abandoned mining and one where reclamation has been practiced is noticeable. The data from the first phase of this investigation seem to indicate that abandoned underground and strip mines are the sources of most acid drainage. Tailings piles, mine dumps, and pumpage from working underground mines also contribute acid drainage in several locations. The studies of the Snow Fork and Huff Run basins, in which sources of acid drainage were definitely identified, support the findings from the first phase.

The absence of acid drainage from reclaimed and working strip mines, noted in both phases of the investigation, emphasizes the importance of rapid reclamation in the prevention of acid drainage. When the sulfur-bearing materials associated with coals are exposed to chemical weathering, acid drainage occurs; when they are not exposed, acid drainage is prevented.

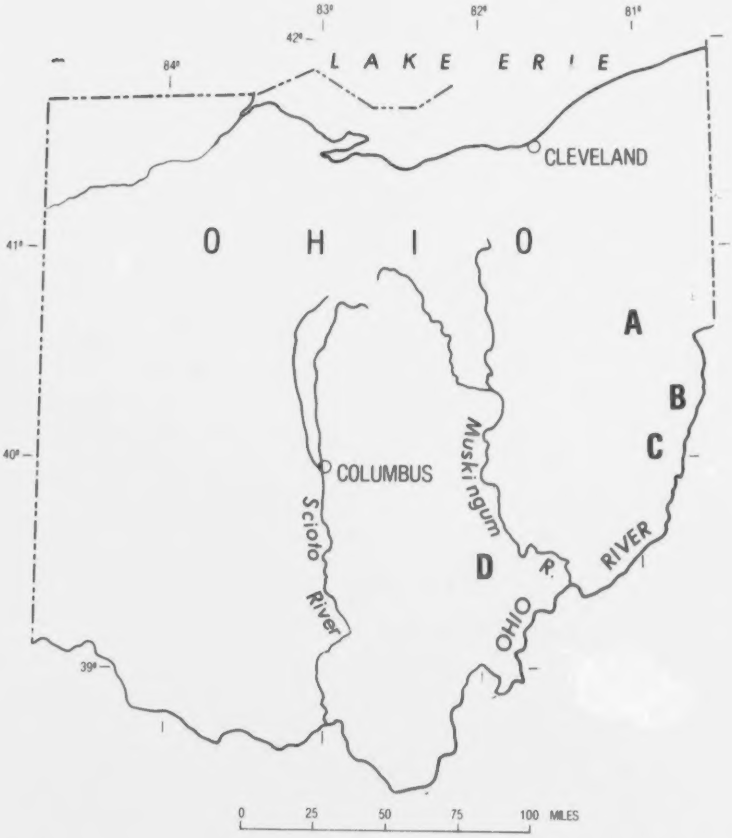

Figure 3.

Basins studied in phase 2 (clockwise from north: A. Huff Run, B. South Fork Short Creek, C. Spencer Creek and D. Snow Fork).

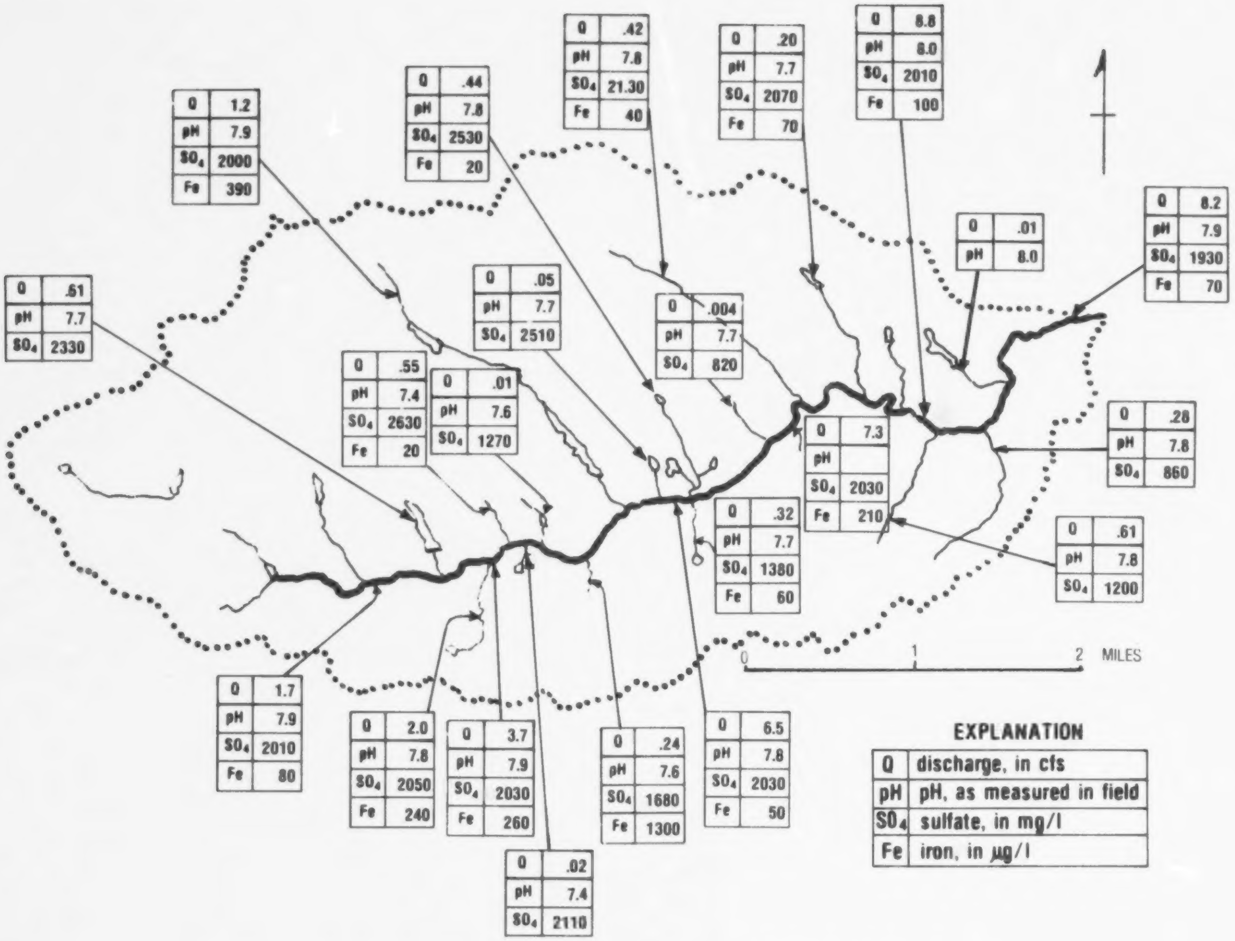
Q 1.2
pH 7.9
SO4 2000
Fe 390
Q .44
pH 7.8
SO4 2530
Fe 20
Q .42
pH 7.8
SO4 21.30
Fe 40
Q .20
pH 7.7
SO4 2070
Fe 70
Q 8.8
pH 8.0
SO4 2010
Fe 100
Q 8.2
pH 7.9
SO4 1930
Fe 70
Q .01
pH 8.0
Q .61
pH 7.7
SO4 2330
Q .05
pH 7.7
SO4 2510
Q .004
pH 7.7
SO4 820
Q .55
pH 7.4
SO4 2630
Fe 20
Q .01
pH 7.6
SO4 1270
Q 7.3
pH
SO4 2030
Fe 210
Q .28
pH 7.8
SO4 860
Q .32
pH 7.7
SO4 1380
Fe 60
Q .61
pH 7.8
SO4 1200
0 1 2 MILES
Q 1.7
pH 7.9
SO4 2010
Fe 80
Q 2.0
pH 7.8
SO4 2050
Fe 240
Q 3.7
pH 7.9
SO4 2030
Fe 260
Q .24
pH 7.6
SO4 1680
Fe 1300
Q 6.5
pH 7.8
SO4 2030
Fe 50
Q .02
pH 7.4
SO4 2110
EXPLANATION
Q discharge, in cfs
pH pH, as measured in field
SO4 sulfate, in mg/l
Fe iron, in µg/l

Figure 4. South Fork Creek and tributaries - reclaimed strip mine area.

WATER QUALITY IN THE OIL SHALE AREAS OF WESTERN COLORADO

Introduction

Latest developments in the oil shale industry indicate increased interest in a modified in-situ approach. This would involve initial underground mining, followed by rubblization, and in-situ retorting. In Colorado the modified in-situ method will most likely be utilized to produce the shale oil in the Parachute Creek Member of the Green River Formation. The Parachute Creek Member consists of an upper and lower unit separated by the kerogen rich Mahogany Zone. The Uinta Formation conformably overlies the Green River Formation.

Discussion

The objective of the basic-data collection program is to obtain water quality data needed to define predevelopment conditions and to monitor the effects of construction and operation of oil-shale mines, retorts, and spent-shale disposal areas.

Table 4 summarizes baseline water quality data taken from 22 wells penetrating the 3 geologic units likely to be involved in any in-situ development. Noteworthy are the high values for the constituents in the Lower Parachute Creek Member.

Groundwater withdrawals and the disturbance of the aquifer systems will impact the surface water systems. Table 5 indicates the range of baseline water quality values to be found at 3 stream monitoring stations in the area. As can be seen from the data, baseline water quality is relatively good.

Program Discussion

Impending energy developments require that baseline water quality data be obtained prior to such development if the impacts are to be assessed. The impacts of development can be prevented or minimized if correct mining and reclamation techniques are utilized. Therefore existing baseline conditions and conditions in existing and former mining areas must be evaluated.

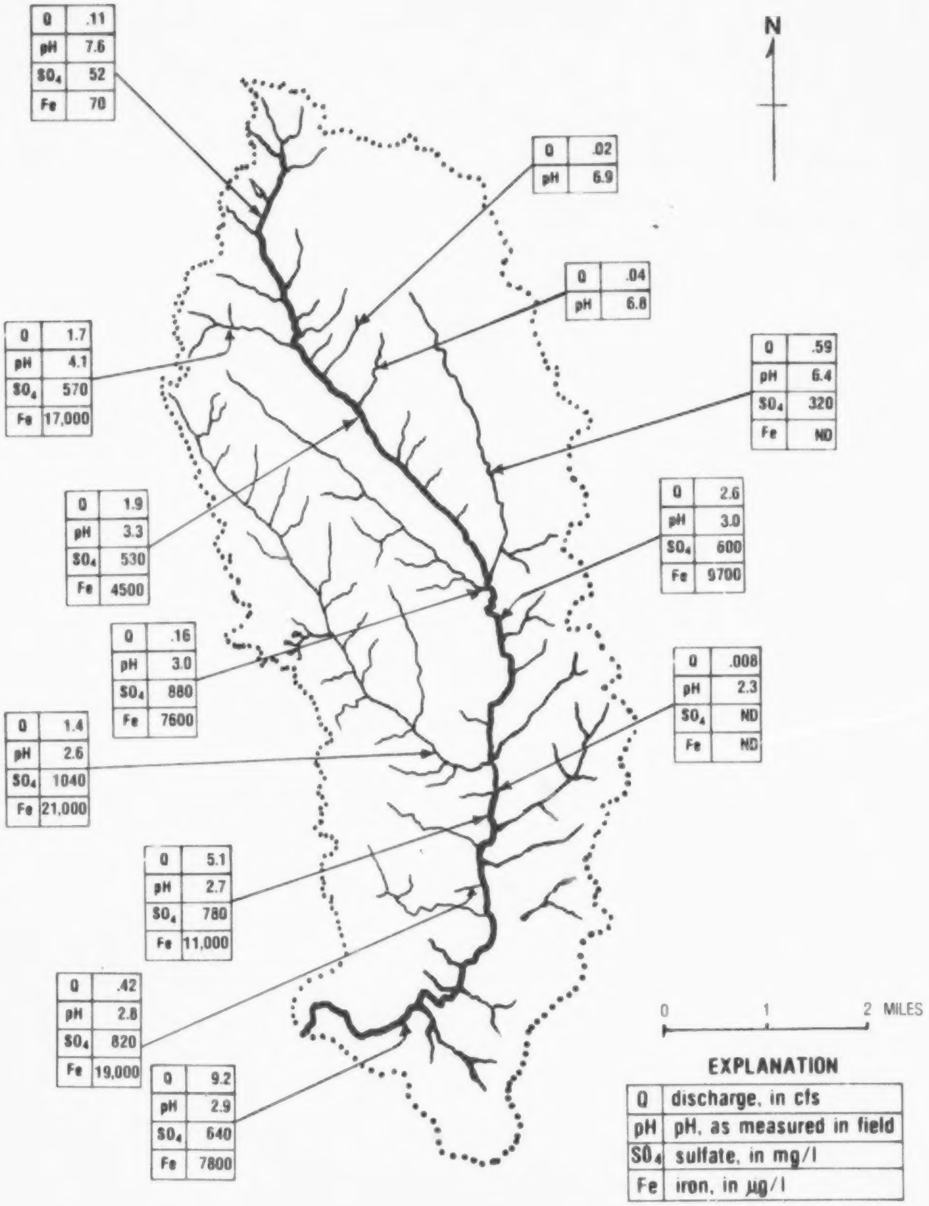
Q .11 pH 7.6 SO4 52 Fe 70
N
Q .02 pH 6.9
Q .04 pH 6.8
Q 1.7 pH 4.1 SO4 570 Fe 17,000
Q .59 pH 6.4 SO4 320 Fe ND
Q 1.9 pH 3.3 SO4 530 Fe 4500
Q 2.6 pH 3.0 SO4 600 Fe 9700
Q .16 pH 3.0 SO4 880 Fe 7600
Q .008 pH 2.3 SO4 ND Fe ND
Q 1.4 pH 2.6 SO4 1040 Fe 21,000
Q 5.1 pH 2.7 SO4 780 Fe 11,000
Q .42 pH 2.8 SO4 820 Fe 19,000
0 1 2 MILES
Q 9.2 pH 2.9 SO4 640 Fe 7800
EXPLANATION
Q discharge, in cfs
pH pH, as measured in field
SO4 sulfate, in mg/l
Fe iron, in µg/l

Figure 5. Snow Fork and tributaries - abandoned underground mining area.

TABLE 4.

AVERAGE CONCENTRATIONS OF MAJOR DISSOLVED CONSTITUENTS, TOTAL DISSOLVED SOLIDS, AND DISSOLVED FLUORIDE IN WATER SAMPLES COLLECTED FROM TEST HOLES PENETRATING THE
A) UINTA FORMATION;
B) THE UPPER PARACHUTE CREEK MEMBER
C) THE LOWER PARACHUTE CREEK MEMBER

	Constituents							
	Dissolved Solids	Ca	Mg	Na+K	HCO_3	Cl	SO_4	F
				(All Data in MG/L)				
a. Uinta Formation								
Max	1720	110	160	321	780	72	880	3.8
Min	470	8.7	15	111	332	5.7	34	.2
Ave	909	38	53	217	536	18	292	1.1
b. Upper Parachute Creek Member								
Max	2220	75	90	860	1930	260	450	18
Min	510	1.1	.6	150	367	5	11	0.5
Ave	828	18	32	309	723	32	153	7.2
c. Lower Parachute Creek Member								
Max	33,300	21	23	14,079	29,400	2,400	200	5
Min	650	4.2	2.8	251	600	5	4.8	19
Ave	3,460	10	10	1,436	3,102	211	66	14

TABLE 5.

THE RANGE IN WATER QUALITY VALUES FOUND AT THREE SURFACE WATER STATIONS IN THE OIL SHALE AREA OF WESTERN COLORADO

Parameter	Parachute Ck near Grand Valley	White River below Meeker	White River above Rangely
Discharge cfs	1.6-128	252-3890	291-2650
Temp °C	0-15.5	0-20.5	0-24
pH	7.2-8.7	7.1-8.6	8.3-8.4
Spec. Cond.-µMHO/CM	520-890	220-740	210-790
*Following Concentrations in MG/L			
Dis. Oxygen	8.3-13.0	6.9-11.6	6.0-7.5
Silica	15-18	10-16	12-15
Calcium	47-62	39-80	66-92
Magnesium	22-41	8.7-24	20-26
Sodium	33-66	7.7-39	55-81
Potassium	1.2-2.7	1.3-2.3	2.1-5.3
Bicarbonate	287-388	116-174	199-238
Sulfate	52-130	38-180	150-280
Chloride	2.1-7.8	5.7-38	27-28
Fluoride	.3-.7	.2-.3	.2-.4
Total Nitrogen (N)	.65-1.7	.18-.64	.38-20
Total Organic Nitrogen (N)	.13-.93	.10-.48	.39-19
Total Ammonia (N)	.00-.04	.00-.07	.00-.00
Total Kjeldahl Nitrogen	.13-.96	.12-.48	.38-19
Total NO_2 and NO_3 (N)	.47-1.3	.00-.20	.00-1.1
Total Phosphate (P)	.00-.20	.00-.22	.03-1.3
Total Organic Carbon (C)	2.4-18	1.6-8.6	9.8-71
Dissolved Solids	315-519	171-477	460-618
Hardness	210-320	130-300	270-310
**Following Concentrations in µG/L			
Boron	30-120	30-50	80-440
Dissolved Iron	0-70	50-60	60-80
Dissolved Manganese	0-10	20-26	5-10
Dissolved Arsenic	2-5	2	2
Dissolved Cadmium	0-1	0-<3	0-<4
Dissolved Chromium	0-10	3-10	4-10
Dissolved Copper	0-10	1-2	4-5
Dissolved Lead	0-<10	1-<3	1-<4
Dissolved Manganese	0-10	20-26	5-10
Dissolved Strontium	90-1400		
Dissolved Vanadium	6.4-11	.9-<2.0	1.1-<2.0
Dissolved Zinc	0-20	0-<3	0-<4
Dissolved Selenium	0-2	1	2
Dissolved Mercury	.0-.1	.0	.0

WESTERN COAL AND OIL SHALE - GROUNDWATER QUALITY MONITORING RESEARCH AND DEVELOPMENT

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INTRODUCTION

A part of the national goal to reduce dependance on foreign oil is to be met by increased production and use of fossil fuels. A critical evaluation of the consequences of an accelerated attempt at this objective is necessary since serious environmental impacts may result from extraction and processing of fossil fuels. These impacts should be anticipated and avoided to the extent possible. Any decision to accept environmental damage, such as a reduction in groundwater quality, should be a conscious one based on the best information and analysis available.

Western low sulfur coal and oil shale constitute two of the nation's most abundant energy resources. Surface mining of Western coal is accelerating rapidly. In 1972, production was about 28 million tons. By 1980, annual production is expected to be 176 million tons.[1]

About 17,000 square miles (11 million acres) in Colorado, Utah, and Wyoming are believed to contain oil shale of potential value for commercial development in the foreseeable future.[2] Development of oil shale in the United States has taken place only on an experimental scale because crude petroleum has been available at lower development costs. The nation's projected future energy needs are so large, however, that it is necessary to examine the possibility of supplementing the conventional domestic oil and gas deposits with fuels from oil shale.

The mining of Western coal and oil shale is expected to have widespread effects on topography, drainage patterns, recharge areas, and groundwater flow patterns. Impacts on groundwater quality will result from use of water, leaching of spent shale, injection of mine water and upward movement and surface discharge of saline waters. Impacts may also be caused by accidental releases of low quality mine water, including failure of evaporation ponds, subsidence due to collapse of retort chambers, and any accidental spillage of processing effluents, chemicals, and waste products.

In association with the growth of these two industries it is anticipated that there will be scattered, uncontrolled point sources of sewage that could lead to bacterial problems and that industrial wastes containing toxic materials, chemicals, oil and grease, heavy metals, and odorous substances will be released.

Passage of the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500), together with the recently enacted Safe Drinking Water Act (P.L. 93-523), provides EPA with the responsibility to initiate effective programs to deal with groundwater pollution. P.L. 92-500 directs, in Sections 102(a), 104(a), and 106(e), that programs be developed to improve, maintain and monitor groundwater quality. Part C of P.L. 93-523 provides for the protection of groundwater quality.

PROJECT AREAS - DESCRIPTION AND SIGNIFICANCE

To determine the impact of Western coal and oil shale development on groundwater quality and to describe and field test the most appropriate monitoring system, two areas were selected for study. The project is being conducted under a research contract with General Electric-TEMPO. The areas were selected where extensive development was being projected - Campbell County, Wyoming and oil shale tracts U-a and U-b in northeastern Utah.

Campbell County is reported to contain 50.4 percent of Wyoming's coal resources and 84 percent of its known strippable coal. More than 69 billion tons of coal underlie Campbell County at depths of up to 3,000 feet. At least 20 billion tons lie within 200 feet of the surface and therefore recoverable by strip mining methods.

Demand for low sulfur coal from Campbell County is increasing at unparalleled rates. By 1978, Campbell County will undoubtedly be the largest coal-producing county in Wyoming. Production estimates range from 62 to 77 million tons per year by 1980 and 84 to 152 million tons per year by 1985.[3] Initially, almost all this coal will be exported to electrical power plants in as many as 13 states as far east as Indiana and as far south as Texas and Louisiana.

In related in-state activity, one coal-fired power plant is under construction east of Gillette. When completed, this 330-megawatt plant will have announced plans to build coal gasification plants in Wyoming by 1980 and one of these is planned to be built in Campbell County. Forecasts of other mines, slurry-pipelines, power plants, and gasification and liquefaction plants are rumored, but not confirmed.

Some of the richest oil shale deposits are located in northeastern Utah. It is estimated that the average thickness of the oil shale sequence that averages 30 gallons of shale oil per ton is about 45 feet in Tract U-a and 50 feet in Tract U-b. The oil recoverable from Tract U-a by underground mining methods is estimated to be 244.4 million barrels, and 265.8 million barrels for Tract U-b. Overburden above the principal oil shale beds ranges from 300 to 1,250 feet.[4]

Groundwater usage in coal strip mining varies with the stage of development. The principal uses of water in the coal mining operations are: dust control on access and haul roads, revegetation of spoils dumps, and dewatering where the coal seam is an aquifer or below the water table.

If the mining operation is planned to eventually include coal conversion plants, increased amounts of water will be required for such purposes as feedwater to high-pressure boilers for steam generation, cooling tower makeup water, and demineralizer and softener regeneration water. Associated with coal conversion plants will be the creation of new industrial bases.

The water requirements for oil shale development and processing can be divided into two categories - process water and domestic water. Process requirements will involve water for mining and crushing, retorting, shale oil upgrading, spent shale disposal, power requirements, revegetation, and sanitary use.

The demand for water for a 'unit' 50,000 barrel-per-day underground mine followed by surface processing is expected to range from 6,800 to 10,600 acre-feet per year.[4]

TECHNICAL APPROACH AND PROJECT OBJECTIVES

Monitoring Methodology

Groundwater availability and usage can usually be determined without much difficulty. Impacts on groundwater quality from mining are much more difficult to assess. A typical misconception is that baseline or background monitoring systems can also be used to assess the impact of man's various activities on groundwater quality. This philosophy has been adopted by many because in certain situations, e.g., air and surface water quality monitoring, the time lag discharge of the potential pollutants into the environment and a measureable response is small, a few hours or days. This is not true in most cases of subsurface pollution. Many years or even decades may pass before a change in groundwater quality is observed. Once degradation of the subsurface regime has taken place, it is extremely difficult and often impossible to remedy.

The reasonable approach to this problem should be to monitor potential sources of pollutants before they enter the subsurface or the less accessible groundwater itself.

Under a previous EPA contract, General Electric-TEMPO developed a predictive methodology for monitoring groundwater quality. The methodology as it pertains to the coal and oil shale study areas is summarized as follows:

(1) inventory and prioritize the potential sources and causes of groundwater pollution within a given project area;
(2) carefully examine and interpret the background information and data on groundwater flow and groundwater quality;
(3) evaluate the mobilities of pollutants from the identified potential sources of pollution and points of discharge into the groundwater system;
(4) assess the gaps and needs of the existing groundwater quality monitoring program;
(5) design a monitoring program based on the identification of the existing program deficiences and/or the inventory of potential sources and causes of groundwater pollution;
(6) implement the monitoring program at the field level and monitor its operation until it is functioning smoothly enough to be turned over to the designated monitoring agency; and
(7) prepare a final report on the results of the research and monitoring efforts which will serve as a guide in the design and operation of groundwater quality monitoring programs for other similar coal or oil shale mining locations.

Progress to Date

The first major task is to collect, organize, and interpret the background data. Scheduled time for this task is approximately one year. At the time this paper was written, much of the existing background data had been collected, but only partially interpreted. The interpretation is proceeding as prescribed by the monitoring methodology, i.e., with the potential groundwater pollution source inventory. The background data have been carefully reviewed to identify potential pollution sources, and then each mine within the project areas will be visited to see if these sources could be identified and if the methods of waste disposal prescribed in the Environmental Impact Statements (EIS) were actually in use.

As a general statement, most of the mine operators appear to be sincere about meeting their obligations in dealing with the potential pollution sources. However, only a few have an adequate staff or knowledge to deal with these problems. Breakdowns in the chain of responsibility at several mines were apparent in a number of instances, such as not recording the number of trips made by water trucks controlling dust, and no attempt being made to segregate potential toxic materials as was called for in the EIS.

Potential sources of pollution and methods of waste disposal for coal mining can be divided into two major categories - those directly related to the mining can be grouped into nine categories: (1) hydrologic modification; (2) construction; (3) solid waste disposal; (4) settling and evaporation ponds; (5) dust control; (6) blasting; (7) stockpiling; (8) sanitary wastes; and (9) miscellaneous related activities.

Important non-mining pollution sources fall into four categories: (1) solid waste disposal and sewage treatment; (2) sanitary wastes from other small urban areas; (3) oilfield wastes; and (4) agricultural sources, including fertilizers and animal wastes.

Hydrologic modifications are likely to become one of the major sources of pollution on the mine sites and can be divided into (a) changes in streams and lakes; and (b) changes in earth materials.

A potentially significant source of groundwater pollution is blasting. All of the mines plan to blast either coal or overburden, and large amounts of ammonium nitrate will be used. In a study at the Decker Mine in Montana, it was found that samples of mine effluent occasionally contained very high concentrations of nitrate, probably due to blasting.[5]

Potential pollution sources related to oil shale mining and processing can be grouped as (1) disposal of solid wastes; (2) waste water; (3) construction-related pollution and (4) accident-related pollution potential. By far the largest and most important single possible groundwater pollution source appears to be the spent shale. The spent shale will have a pH of 10.7 - 11.8 and will contain from 0.6 percent to 20 percent soluble salts. The mining operation proposed in the Detailed Development Plan indicates the processed shale will be moisturized to about 10 percent by weight and moved by conveyor belt to the disposal site. The spent shale generated in the 50,000 barrel-per-day operation is supposed to be disposed of in a 130-acre area with the ultimate depth of spent shale being about 100 feet for a 20-year operation.

Large quantities of industrial waste may be generated by the processes of recovering and treating the shale oil. These wastes are scheduled to be hauled to the spent shale pile, moisturized, spread, and covered with spent shale. The most significant of these wastes from the standpoint of pollution potential are the spent catalysts and activated carbon and diatomaceous earth filters which have become clogged. These wastes will total about 1,700 tons per year. Along with the filters and catalysts, about 700 tons per year of rather inert wastes will be buried.[6]

Near-Term Objectives

At the end of the first year, a pollutant-source prioritization report to identify the pollution sources needing the most detailed monitoring will be completed for each project area. As a first criterion, the sources of largest waste volume, longest persistence, highest toxicity, and concentration of specific pollutants will be identified.

The second criterion will be based on the mobility of the pollutants as they migrate downward through the soil and through the aquifer toward eventual points of discharge or water usage. The mobility of the pollutants will be dependent upon the method of waste disposal, the waste loading, and the sorption and chemical reactions taking place in the soil and saturated portions of the aquifer.

The last criterion in the prioritization scheme will be a function of the known or anticipated harm to the users of the groundwater. Based on the knowledge of pollutant mobility, it will be possible to estimate the impact of the identified sources of pollution in the project areas at specific points of usage at varying distances from the sources. This third criterion is thus based on the quality of water that may be pumped from wells for various uses in the area.

At the end of the first year, a report will be completed which details oil shale mining approaches, kerogen recovery processes, and hydrogenation processes. Since the processes for oil shale extraction have not been formalized, a summary of the existing alternative processes and the research done on defining the anticipated organic and inorganic pollutants from each of these processes must be done in conjunction with the evaluation of the existing groundwater monitoring approaches for test and small-scale oil extraction sites.

At the end of fifteen months, a monitoring program design for the coal aspect will be submitted for review. The design will be based on the prioritization report and the observed data and information gaps in the existing monitoring programs within the project area. Eighteen months into the study, a monitoring program design for the oil shale mining and processing operations will be submitted.

Long-Term Objectives

Once there is an approved monitoring program, field monitoring activities will be implemented. A field office in Gillette, Wyoming, will be manned by full-time personnel whose responsibilities will be to insure that the monitoring activities are conducted on schedule and that professional techniques are maintained in the field activities.

After the implementation of the monitoring programs, it will be necessary to establish procedures to organize and interpret the current monitoring data so as to define quality trends, new pollution problems, regions of improvement, and effectiveness of pollution control activities with regard to groundwater quality.

The result of the monitoring program will be the providing of information on groundwater quality. Consequently, a final task will be to disseminate the information gained as guidelines for monitoring groundwater to agencies and organizations concerned with making management decisions.

An important by-product of the project will be the alerting of action and enforcement agencies on critical problems and situations discovered withing the project area. These may involve, for example, detection of hazardous or toxic pollutants which could imminently affect a nearby drinking water supply. Prompt reporting and specialized follow-up monitoring efforts for controlling emergency situations will be essential.

It is anticipated that at the conclusion of the project the monitoring programs will be integrated into the monitoring activities of the locally designated monitoring agencies. This activity will tie into the main goal of the project which is the development of a manual to show how groundwater quality monitoring programs for similar coal strip mining and oil shale extraction sites can be designed.

IDENTIFIED RESEARCH NEED: GROUNDWATER MONITORING OF IN SITU DEVELOPMENT OF OIL SHALE

An additional research need which concerns the oil shale aspect of the project has been identified. At the time of the contract execution for this project, it appeared oil shale would be developed by conventional mining methods followed by surface retorting; therefore, the study area was selected on this basis. However, industry plans for surface retorting of oil shale were delayed in September 1976, when the holders of the Federal leases in both Utah and Colorado were granted a one-year suspension by the U.S. Geological Survey on the lease agreements concerning development lease fees. A few weeks later, Occidental Petroleum Corporation formally joined with Ashland Oil Corporation in the lease agreement for Oil Shale Tract C-b (located in the Piceance Basin of northwest Colorado), and the two companies announced that they intended to develop the oil shale in the tract by use of a modified in situ process. Since the process had been tested extensively in another location, the companies stated that it was feasible for them to develop oil shale by this method on a commercial scale. The initiation of the operation in Tract C-b has resulted in a modification of the already accepted Detailed Development Plan; the modification was submitted to the U.S. Geological Survey in March 1977.

The operating companies in Tract C-a, which is near Tract C-b in Colorado, have also announced plans for in situ oil shale development. There are no similar plans for the Utah tracts and thus, in situ development there appears unlikely in the near future.

Monitoring for potential groundwater quality impacts associated with in situ oil shale development will be difficult. Retort waters produced by small-scale in situ operations have resulted in the identification of a large variety of potential pollutants. Research to date indicates that many of these pollutants have only recently been classified, while others are still under investigation. It is not clear whether the quality of the retort waters from small-scale in situ retorting will be similar to those waters produced by large-scale commercial in situ retorts.[7]

The proposed "modified" in situ processes will require mining of perhaps 20 to 25 percent of the retort block in order to create adequate porosity for in situ retorting. Current plans for Tract C-b call for mined raw shale from in situ retort blocks to be brought to the surface and stored indefinitely in Sorghum Gulch.

Modified in situ retorting operations in northwest Colorado may have impacts on groundwater due to dewatering during mine development and operation; eventual reinvasion of the exhausted retort chambers by the groundwaters; consumptive use of water; possible reinjection of mine water and upward movement and surface discharge of saline waters; accidental release of low-quality mine and retort waters, including failure of surface holding reservoirs; and any accidental spillage of processing effluents, chemicals, and waste products. Storage of the raw shale at the surface may have widespread effects on the topography, recharge areas, and drainage patterns, due to grading and removal of vegetation, and leaching and weathering of the raw shale. Groundwaters may be further affected by subsidence after retort development resulting in aquifer displacement and/or disruption.

To monitor the groundwater quality changes resulting from these conditions will no doubt be more costly and difficult than the monitoring that would be needed for operations (such as those proposed for the Federal Tracts in the subject project) involving subsurface mining of oil shale with surface facilities for retorting the shale. Major costs can be anticipated in the monitoring of the water quality effects in the subsurface vicinity of the retorting chambers and in the zones where subsidence could be expected to occur.

Shortly after plans for in situ developments of oil shale were announced, EPA headquarters suggested modifying the subject project to include research monitoring of the groundwater quality impacts of the in situ developments. Close examination of the project revealed that two conditions are apparent: First, the planned in situ developments are in northwest Colorado instead of in Utah where the study area is established by contract terms. Secondly, the cost for studying groundwater effects and monitoring methods related to in situ processes will be higher than the amounts provided in the project for study of oil shale. The contractor was asked to submit a proposal to show the options for modifying the project. This proposal has been prepared and is now being considered by EPA.

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WESTERN ENERGY-RELATED OVERHEAD MONITORING PROJECT

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The technology of remote sensing has advanced considerably over the last 10 years. The most significant step has been the development of automated computer processing techniques which use data acquired from overhead multispectral scanners and spectral pattern recognition algorithms to classify surface materials on the ground. Although the techniques vary and cannot be discussed in depth here it has been demonstrated that these techniques can be used to classify surface materials and to determine surface acreage of the material with accuracies generally between 80 and 95 percent. Because this accuracy is comparable to accuracies obtained using conventional methods and because remote sensing techniques offer uniform and standardized data handling methods, speed in analysis, reduced data-acquisition time, reduced site visitation costs, and data and information formats which can be systematically integrated with data and information from other sources using digital techniques, operational procedures can be developed and applied to energy extraction problems in a cost-effective manner.

In particular, the capability to classify surface vegetation from aircraft and satellite data in densely vegetated areas such as the Eastern United States allows the assessment of many environmental parameters since vegetation is a sensitive indicator of its environment. In some areas of the Western United States where vegetation is sparse, new techniques are being developed under this project to determine the extent to which vegetation may be classified with varying percentages of vegetation cover. In addition, classification techniques using aircraft-acquired data have proven very successful in identifying various conditions of soil such as topsoil, scraped soil or piled overburden at strip mine sites.

Data from other aircraft sensors such as the Laser Terrain Profiler have shown high potential for measuring such parameters as terrain roughness and slope as indicators of rehabilitation. Future activities under this project will pursue the continued development of such techniques. Techniques employing multispectral scanners on aircraft for data acquisition are most suited for site specific problems such as monitoring and evaluating coal strip mine rehabilitation efforts. The reason is that the data may be acquired at high resolution for investigating such parameters as individual species in revegetated areas and vegetation densities in sparsely vegetated areas such as the Western Great Plains. The use of aircraft-acquired data, however, does require additional processing effort over satellite-acquired data because the scanner mounted in the aircraft is subjected to normal aerodynamic motions. This reduces the utility of aircraft data in applications requiring precise geometric registration of data to a map base. In addition, the large volume of data resulting from the high resolution makes it undesirable to acquire aircraft data over large geographic areas.

Techniques employing multispectral scanners on satellites (Landsat) for data acquisition are presently most suited for regional applications such as large area land use planning or determining rehabilitation potential for strip-mined lands. Because of the repetitive coverage and the geometric location and pointing stability of the spacecraft, the scanner data can be rectified and geographically referenced to the surface of the Earth. This allows the data to be easily integrated with data from other sources and allows the detection of surface changes from one data set to the next on a point-by-point basis. This can be done very rapidly and precisely using computer-implemented techniques. Using these techniques, a data base and information system can be constructed for specifying environmental baselines and determining the changes thereafter. A present limitation of the Landsat system is that its resolution allows surface cover identification down to 1-acre areas. Near-future satellite systems will provide identification down to 1/4-acre areas which will have practical potential for application to site specific problems such as strip mine rehabilitation.

During the summer of 1975, the National Aeronautics and Space Administration (NASA) entered into a 5 year project with the Environmental Protection Agency (EPA). The purpose of this interagency project, funded by EPA, was to transfer hardware and software techniques for processing remotely sensed digital data from NASA to EPA, so that EPA would be capable of establishing and maintaining a fully operational energy related overhead monitoring system. This system would not only incorporate maximum utilization of EPA's present aircraft capabilities, but would allow for the integration of currently available (Landsat) and proposed satellite multispectral scanner data. Personnel skills necessary to implement such a highly technical system would also be transferred during the project.

Both agencies have designated laboratories through which the 5 year plan will be implemented. NASA/Earth Resources Laboratory located in Slidell, La., and the EPA/Environmental Monitoring and Support Laboratory in Las Vegas, Nev., are the two agency laboratories involved.

The entire project has been divided into three phases. Phase I was an 18 month project segment, during which time existing NASA remotely sensed data acquisition, data analysis, and information producing capabilities were applied to digital data acquired by both Landsat and aircraft systems over coal strip mines in the western United States. A data processing system was defined, assembled, and transferred to EPA in January 1977. Key EPA personnel also received training in the use of a similar data processing system during November/December 1976 at NASA. The Low Cost Data 'mini-computer" Analysis System, (EPA-LCDAS) assembled for EPA, is composed of a mini-computer, associated rotating memory (disc memory), interactive image processing system (e.g., color cathode ray tube display device with hardline connection to the computer), tape drives, line printer, electrostatic plotter, and color strip film recorder (stand alone version). This system is capable of processing Landsat and aircraft acquired multispectral scanner data as well as data from currently defined future multispectral scanner systems.

In addition to the EPA-LCDAS assembled at NASA for subsequent transfer to EPA, an airborne multispectral scanner system was also defined. The scanner system, delivered and installed into an EPA aircraft and integrated with data processing/analysis components, is providing EPA with the total capability to collect and process digital data entirely on its own system, thus accomplishing the major goal of Phase I of the project.

Phase II of the project began January 1, 1977 and will last for 18 months. During this phase, the EPA will use the system for monitoring purposes, with NASA assistance should any technical problems arise. Also during this time, NASA would investigate problems specifically defined by EPA for additional research. Such problems would be associated with coal strip mine, mine-mouth power plant, oil shale, and geothermal energy related activities. New techniques developed to solve these problems would be transferred to the EPA at the end of this phase.

Phase III will be a 2-year project, during which time EPA will test the system in a fully operational mode. NASA will provide continued assistance in the use of the system and any additional capabilities as developed during Phase II. It is anticipated that Landsat follow-on data will be available during this phase, providing satellite data of better resolution and spectral selectivity than presently available. Processing capabilities for such data will be developed and transferred during this time period, if such data become available.

REMOTE SENSING OF SULFUR DIOXIDE EFFECTS ON VEGETATION

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INTRODUCTION

The Tennessee Valley Authority (TVA) is studying the effects of sulfur dioxide (SO_2) emissions from large coal-burning power plants on vegetation by remote sensing, that is, by studying the phenomenon from a distance with no direct contact.

The objective of the project is to test, refine, and develop instruments and techniques for remotely sensing the effects of SO_2 on vegetation in the vicinity of power plants. The work involves gathering and analyzing spectral reflectance data by using imaging and nonimaging sensors and an array of instrument platforms, including cherry pickers, helicopters, and airplanes.

Before 1975, very little information was published on remote sensing of the effects of air pollution on vegetation. Many of the applicable studies deal with the use of infrared color photography for mapping and for detecting disease in crops and trees. Miller et al. (1) studied the effects of ozone on forest species, and Heller (2) and Wert (3), using color film, studied the effects of oxidant air pollution on the foliage of Ponderosa pine in the vicinity of Los Angeles, California. The best combination of films and scales for detecting air pollution effects on trees is reported to be Anscochrome Daylight 200 color film with a didymium filter and a large scale (1:1600).

In 1971, Zealer et al. (4) reported the feasibility of using aerial color photography to detect and evaluate foliar SO_2 effects on timber stands near a coal-fired steam plant in northeastern Alabama. TVA cooperated with the U.S. Forest Service in this study. The authors concluded that very large scales (1:800 to 1:1584) and normal color film were the best combination for the task. A follow up study with photography or multispectral scanning to detect timber species affected by SO_2 would be desirable.

Several published reports describe attempts to use satellite data to detect damage and alteration to vegetation caused by emissions from a zinc smelter. Fritz and Pennypacker (5) were unable to differentiate between an affected stand of eastern white pine and a healthy one, although Wiegand (6) earlier had successfully used satellite data to differentiate between chlorotic (iron-deficient) and normal grain sorghum plants. Affected areas as small as 1.1 hectares could be detected by digital techniques. More study is required to resolve the contradictory results of using satellite platforms to detect the effects of SO_2 on vegetation. Limits of detection must be determined and defined. Murtha (7) describes a method for evaluating SO_2 damage to forest lands in Canada from flying heights as great as 12,200 m and image scales as small as 1:160,000. However, the successful application did not include zones of "light injury."

German scientists have used aerial infrared color photography to detect injury to trees caused by air pollution. Large image scales on the order of 1:5000 seem to be favored over medium or small scales (8).

TECHNICAL DISCUSSION

In 1975, TVA began a series of remote-sensing overflights in the vicinity of Shawnee Steam Plant in western Kentucky. The Environmental Protection Agency (EPA) Region IV helped TVA arrange an overflight for multispectral scanning out of Bay St. Louis, Mississippi; the plane, equipment, and image analysis assistance were provided by the Earth Resources Laboratory at the National Aeronautics and Space Administration (NASA) Johnson Space Center. This overflight and a series of overflights for aerial photography were made by TVA after vegetation was exposed to SO_2 in July 1975. Results of TVA's interpretation of the photographs and NASA's digital analysis of the scanner imagery were negative. More than a week elapsed between the SO_2 exposure and the overflights, and it is probable that the visual effects of the injury to vegetation were masked by new growth. An extensive collection of field data resulted in an excellent description of the patterns of vegetation injury that did exist.

Work during 1976 and 1977 has been organized around certain species of plants and three principal tasks. The species being studied are soybeans [Glycine max (L.) Merr.], cotton (Gossypium hirsatim), winter wheat (Triticum aestiuum), Virginia pine (Pinus virginiana), loblolly pine (Pinus taeda), white pine (Pinus strobus), shortleaf pine (Pinus echinata), hickory (Carya sp.), and red oak [Quercus rubra (L.), Q. falcata]. This list of crops and trees is subject to revision as work progresses. The trees will be studied only under natural conditions, but the crops will be grown and studied under both natural and controlled conditions (prepared field plots and greenhouses).

The principal tasks of the project are (1) photographic recording and image analysis for plants fumigated in the laboratory under controlled conditions, (2) spectroradiometry, and (3) collection and analysis of images from airborne sensors and cherry pickers.

Present work on this project involves Widows

Creek and Shawnee steam plants (figures 1 and 2). Activities scheduled for the 1977 growing season include (1) detailed laboratory work involving short-range remote sensing and image analysis, (2) field measurements of reflectance under controlled and natural conditions, and (3) remote sensing from aircraft at low and medium altitudes. Satellite (Landsat) data will be analyzed after 1977. The activities for 1977 are detailed below.

1. Closeup photographs will be taken of plants fumigated in a laboratory chamber under controlled conditions. The photographs will be enhanced with a Spatial Data Systems Color Image Analyzer (figure 3), which will help in the interpretation of data extracted from the photographs.

2. The Gamma Scientific Scanning Spectroradiometer (figure 4) mounted on a cherry picker or ladder truck and in a Bell helicopter will be used to gather data on spectral reflectance that pertain to healthy and affected crops and trees. A series of spectral curves for soybeans is shown in figure 5.

3. TVA will make a series of overflights of Shawnee and Widows Creek steam plants after an SO_2 exposure, should one occur, to obtain aerial true-color and infrared color photographs.

4. A series of overflights will be made of the same areas with a multispectral scanner--in this case, a Daedelus model 1260 scanner owned by EPA's National Environmental Research Center (NERC) and mounted in an aircraft contracted by EPA. This work has been arranged by TVA on a suborder basis and is tentatively scheduled for August 1977.

Laboratory fumigations and photography of the affected plants are in progress. Field operations with the scanning spectroradiometer and overflights will take place in midsummer 1977, when crops and trees are most susceptible to the effects of SO_2. The purpose of all phases of this work is to support image analysis.

Work after 1977 will concentrate on remote sensing with satellite data. Satellite imagery now available does not show promise for detecting subtle effects of SO_2 exposure on vegetation because of limitations in image resolution at 80 m.

PROGRAM DISCUSSION

Although all project phases are underway, little can be said about results until late 1977. If a particular task shows unusual promise, proportionately more emphasis will be given to it at the expense of other tasks. For example, spectroradiometry now appears to be the most promising

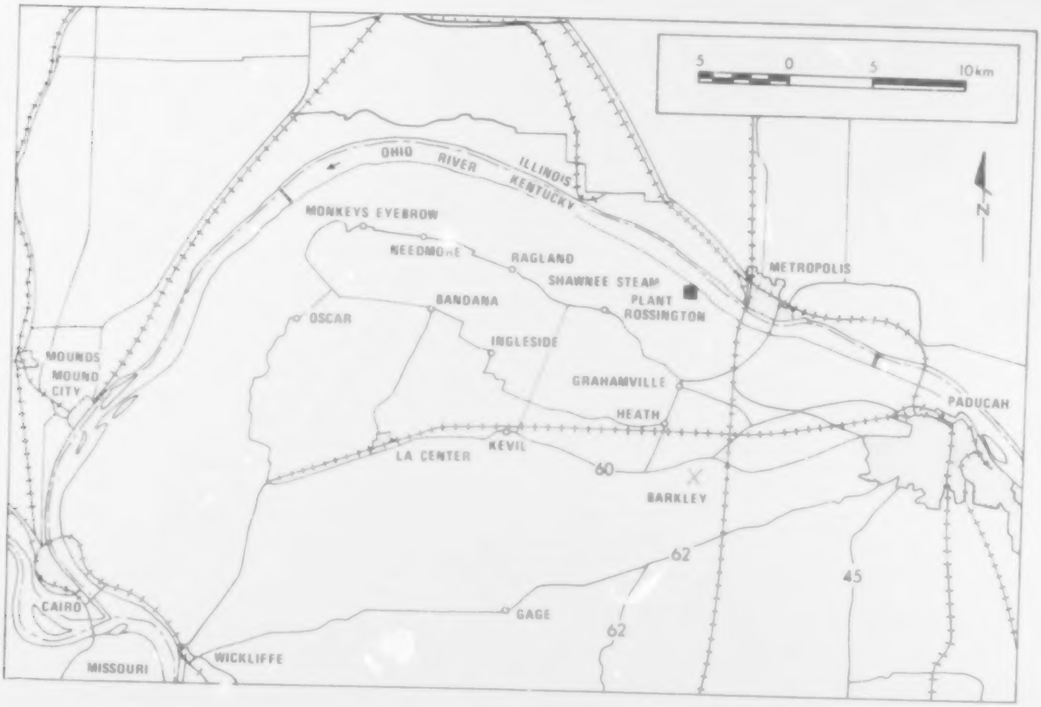

Figure 1.

Shawnee Steam Plant and vicinity, western Kentucky and southern Illinois.

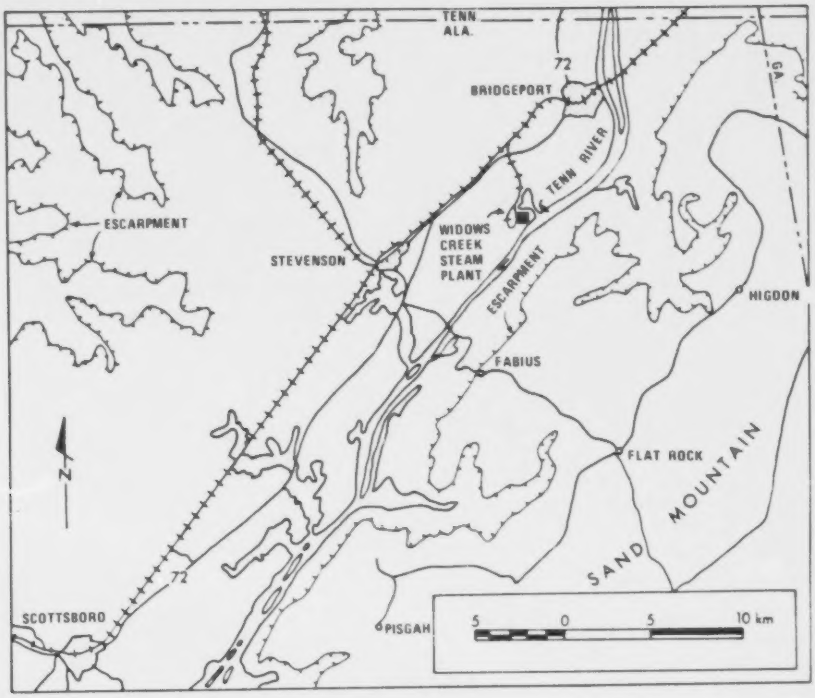
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Figure 2. Widows Creek Steam Plant and vicinity, northeastern Alabama.

Figure 3. Spatial Data Systems Color Image Analyzer (color densitometer), at NASA Marshall Space Flight Center

Figure 4. NASA's Gamma Scientific Scanning Spectroradiometer, showing telescopic head with control unit, x-y recorder, and battery power pack behind tripod.

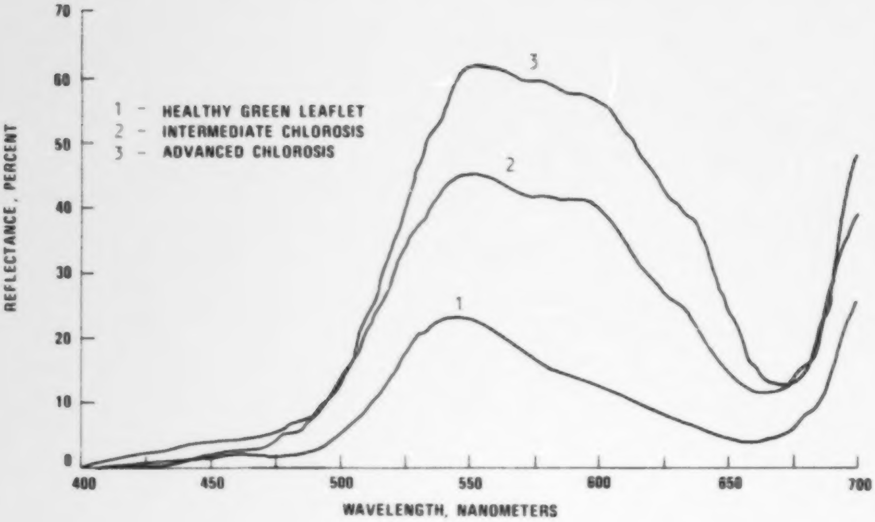

Figure 5.

Changes in reflectance of a soybean leaflet in various stages of stress. Measurements obtained with Gamma Scientific Scanning Spectroradiometer.

technique, but later work (after 1977) will concentrate on remote sensing from satellite platforms and digital analysis of the data. Landsat-C will be launched in September 1977 and is expected to be more useful than earlier satellites because its sensors are better than those of Landsat-1 and -2.

Once the limits of detection for patterns of effects of SO_2 exposure on vegetation are known, an operational system can be organized so that routine overflights by aircraft and satellites can be used to monitor the injury. This information will enable corrective action. A system that would allow nearly real-time response may be possible, perhaps in the mid-1980s. There is a great potential for saving manpower if the tasks of manually mapping the boundaries of areas affected by SO_2 could be augmented by overflights for aerial remote sensing. Images obtained during aerial missions using multispectral scanners, combined with (1) information from spectroradiometric measurements and (2) reflectance data from plants fumigated with SO_2 in controlled chambers may provide the key for successfully detecting patterns of injury from a distance.

To date, TVA's only successful aerial detection of the effects of SO_2 on vegetation has been with oblique true-color photographs made in 1975 with a hand-held camera over a pine forest near a steam plant **(Figure 6)**. A color enhancement of the image area apparently affected by SO_2, produced on the Spatial Data Systems Color Image Analyzer, is shown in black and white below the normal, oblique-angle photograph. The failure to date to obtain vertical aerial images that show the boundaries of areas affected by SO_2 could be the result of poor timing or inappropriate flying height. The experiments to be conducted during the summer of 1977 should resolve these questions.

CONCLUSIONS

From a comparison of extensive ground-truth field data with the results of multispectral scans and conventional photographs made during a series of overflights in the vicinity of Shawnee Steam Plant in 1975, the principal investigator has drawn several tentative conclusions that will be applied to future studies of remote sensing:

1. Timeliness is critical; overflights should normally occur within about seven days after an exposure, but the exact limits are controlled by the weather because rapid plant growth obscures the injury caused by SO_2.
2. Incomplete plant canopy cover creates problems because of the interference of soil background in the scene being interpreted from the image. This problem is particularly apparent in images of row crops. Therefore, future overflights should be conducted late in the growing season when crops are mature and the canopy is continuous.
3. A variety of flying heights should be used over selected sites to determine the optimum image scale for detecting the effects of SO_2 exposure. A number of sensors and combinations of films and filters should be used.
4. The collection of ground-truth field data in 1975 was entirely adequate to support the project. Future exercises should be conducted similarly and could be restricted to a smaller area without affecting the results of the remote sensing program.

It is too soon to draw conclusions on the value of laboratory experiments involving photo-

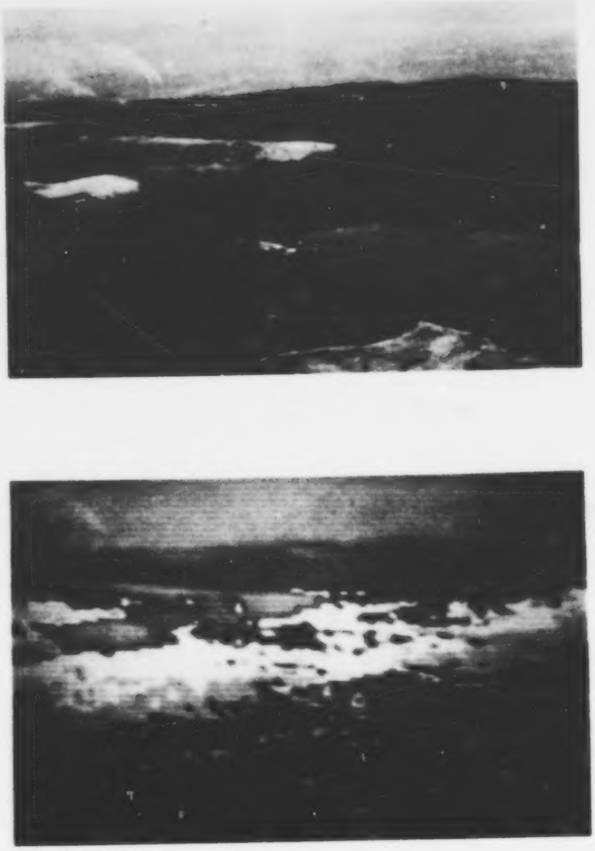

Figure 6. Oblique aerial photograph (top) taken at low altitude of a pine forest affected by SO_2 from a nearby steam plant and electronic enhancement (bottom) of the same scene. Light tones on enhancement indicated affected trees. Photos taken in 1975. Originals in color.

graphic recording of the results of experiments in fumigation chambers, enhancements of color images, and spectroradiometric measurements. By late 1977, these experiments should be completed, and several remote-sensing overflights should have been conducted. The combined information should yield some firm conclusions concerning the detectability of areas affected by SO_2 by remote sensing.

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POLLUTANT MEASUREMENT METHODS DEVELOPMENT SUPPORTED BY ENERGY FUNDS

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INTRODUCTION

It is just as true today as it was when Kelvin said it 85 years ago: "When you can measure what you are speaking about, and express it in numbers, you know something about it..." Stated in cybernetic terms, this becomes "Feedback is an essential element of the control loop." Control -- defined as an operation whose objective is the maintenance of some parameter at a predetermined value -- cannot conceivably be a rational process without means for measuring the deviation of controlled parameter from its target value.

The above considerations dictate that any attempt to control air pollution contains an absolute requirement that measurement technology be available for the pollutants of interest. This concept is the foundation-stone of ESRL's methods development program.

For the near-term future (which extends indefinitely, pending a major breakthrough in energy conversion), a major portion of America's resolution of its energy crisis will involve large-scale substitution of coal for liquid and gaseous fuels. In the first years of this reversion of previous trends, this will call for an order-of-magnitude increase in the need for technology designed to minimize emissions of coal-generated pollutants to the atmosphere. Without such control technology, energy-environment trade-offs are likely to be unduly weighted -- in view of the crisis situation -- to the detriment of the environment. And, as we have seen, this needed technology can neither be optimally developed nor efficiently operated in the absence of measurement capability.

It is axiomatic that methods-development research supported by Energy funds will be principally concerned with those pollutants associated with the burning of coal. These include sulfur oxides ("SO_x") or, more specifically, sulfur dioxide, sulfate ion, and free sulfuric acid; also those organic products of coal combustion that may be described as "potential carcinogens," or more broadly "materials of high physiologic impact."

TECHNICAL DISCUSSION

The doctrine of non-degradation of air quality imposed a need, intensified by the energy-oriented proliferation of coal-burning power sources, to quantify atmospheric concentrations of sulfur dioxide well below those measurable with 1975 instrumentation. A pre-existing but dormant ESRL project was judged to offer the best approach to satisfying this need. Its aim was to optimize operation of the flame photometric sulfur detector.

Existing methods for the measurement of sulfate in airborne particles were known to be subject to interference, largely from artifact sulfate generated by oxidation of SO_2 during the sample-collection process. The selected approach to correction of this defect consisted of evaluating alternate filter media, in combination with materially increasing analytical sensitivity in order to permit shorter sampling periods, thus inhibiting artifact formation.

Sulfuric acid mist is one of the oldest known air pollutants, yet its measurement at ambient levels was unknown in 1975. The extreme reactivity of sulfuric acid dictated that its successful measurement must be accomplished in something approaching real time, else it would be destroyed by reaction with either the filter medium or co-collected particles, or both. Collection on a highly inert filter, followed by rapid analysis was selected as a potentially feasible approach.

The separation, identification, and eventual quantification of individual compounds from the incredibly complex mixture of organic materials generated by the combustion of coal presents the ultimate challenge to the analytical chemist. Consideration of the analytical approach to this problem inevitably leads to the selection of a single strategy, combining in synergistic fashion the separative resolution of gas chromatography, the analytic capability of mass spectrometry, and the recognitive skills of the computer. There is today no other technique or combination of techniques that can hope to compete for the assignment.

It has long been recognized that measurements of total suspended particles (TSP) can seriously perturb, by the random inclusion of a small number of large particles, any attempt to correlate particulate pollution with adverse health effects, since the latter must necessarily correlate (if at all) with the respirable fraction of the particle population. As a first approach to the problem, an arbitrary decision was made establishing a dichotomous classification of particles as respirable ($<3.5\mu$ m) or non-respirable ($>3.5\mu$ m). The practice of some earlier workers of constructing histograms showing size distribution with finer resolution was discarded as contributing little to an understanding of health-effect problems.

PROGRAM DISCUSSION

Sulfur Dioxide

The ongoing program leading toward a hypersensitive SO_2 instrument has as its starting

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point an improved version of the Meloy flame photometric analyser, Model 285, in which the manufacturer has optimized the burner housing, improved the electronics, and placed burner and flow controls in a thermostated block. The effect of these changes has been to provide 0.5 ppb sensitivity and to eliminate drift due to changes in ambient temperature. Planned improvement, consisting of a microprocessor that will compensate for effects of changes in barometric pressure upon the flow control system, is presently on course. The final product, a device sensitive to 0.1 ppb and capable of operation aboard small aircraft, is expected to be delivered by 1/1/78.

Sulfate

An elegant method developed by Brosset (Environmental Agency of Sweden) for the microdetermination of sulfate and of strong acid (surrogate for sulfuric acid) was adopted and further improved. Using a Thorin titration for the determination of sulfate and a Gran plot for determination of strong acid, this has been an invaluable aid in studies of particles collected in a variety of atmospheric studies.

Publication of the initial article on Ion Chromatography in 1975 offered, for the first time, a sulfate method that did not depend upon barium precipitation for its operation. ESRL scientists immediately realised the value of this new method, and adopted it as an important tool in studies involving particulate sulfate. It has since been taken up enthusiastically by other EPA laboratories. One important purpose that it is serving is that of distinguishing unequivocally between sulfate and sulfite. A small but important modification of the procedure by which particulate samples are extracted prior to analysis prevents the oxidation of sulfite during sample preparation, and has been used to demonstrate for the first time that airborne particles seldom if ever contain appreciable quantities of sulfite. This is important in that it validates the assumption that total sulfur in a particulate sample is precisely equivalent to sulfate, thus permitting the use of rapid and convenient x-ray fluorescence analysis for total sulfur as a valid measure of sulfate.

Sulfuric Acid

Sulfuric acid mist is efficiently collected on a fluorocarbon membrane filter. Subsequent warming of the filter in a bone-dry stream of air serves to convey the acid to a flame-photometric sulfur detector for readout. In addition to being inert, the fluorocarbon filter material has the further advantage of being difficultly wettable, thus inhibiting the coalescence and consequent interaction of acid droplets with neighboring droplets of other substances collected simultaneously. It is planned to evaluate the effect of co-collected organic material upon acid recovery, by observing the decay (if any) of acid as a function of the time during which the two kinds of particles coexist on a filter.

Organic Pollutants

The extreme sensitivity (parts-per-trillion or beyond) demanded of any scheme for the measurement of combustion-source organic pollutants immediately mandates a sampling procedure that is integrated over some period of time.

Tenax GC, a thermostable porous polymer, has been demonstrated to be capable of retaining the vapors of non-polar substances very efficiently, and of releasing them upon heating. This has become the favored method of sampling for organic vapors in the atmosphere. It is recognized that substances having critical temperatures below 150° are less efficiently captured, and that opportunities for artifact formation exist with some reactive substances; carbon adsorption is used as an alternate trapping medium in such cases. Studies are continuing toward better resolution of the collection problem.

Samples collected as outlined above are thermally transferred to a gas chromatography column containing a stationary phase judged appropriate for those substances thought to be present (usually after preliminary examination using a general purpose column), and fractionation is performed thereon. Column effluent is passed to the inlet of a mass spectrometer, which performs rapid mass scans and records its results on a computer. Subsequently, these scans are compared with computer-stored reference spectra to provide compound identifications.

Fine Particles

Suspended particles represent an area of air pollution measurement that has long been difficult and imprecise. Such particles are not chemically definable, but are categorized solely on the basis of a combination of physical characteristics: their size, shape, and weight are such that they can remain suspended in air for an appreciable (but not defined!) length of time. Some improvement over the time-honored Hi-Vol Sampler method of collecting particles for measurement has been needed. One approach to this has been ESRL's development of the dichotomous sampler. This has led to the production (now under way) of two models -- manual and automated -- that have been carefully designed to permit their being offered to the control-agency community at prices that will hopefully encourage their evaluation on a broad scale. When these become available -- 1978 -- it is hoped that their manifest advantages of improved precision and sensitivity, together with their ability to segregate those particles whose size decrees possible effects upon health, will overcome the tendency to remain locked to an older and far less meaningful technique, simply because "It's always been done that way."

MEASUREMENT STANDARDS FOR AIR POLLUTION MONITORING AND CONTROL ASSOCIATED WITH ENERGY PRODUCTION

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This paper describes those activities of the National Bureau of Standards related to standards needs associated with energy-related air pollution monitoring. This effort is an extension of the NBS base program in air pollution measurement standards and some of the projects described have been supported in part by the NBS base program. The mission of the National Bureau of Standards is to provide standards of measurement and means for allowing measurements to be made compatible with these standards. The task falls to NBS of addressing those problems of greatest national concern. In 1970, NBS initiated its air pollution measurement program. With the implementation of the recommendations of the King Report, the NBS air pollution program has expanded to include the provision of Standard Reference Materials (SRMs) for gaseous pollutants and airborne particulates arising from fossil fuel combustion and for the chemical characterization of fuels and raw materials. In addition, an instrument has been developed to distinguish sulfur compounds in particulates from gaseous sulfur compounds.

Four SRM's have been issued which consist of gas blends of sulfur dioxide in nitrogen in concentrations ranging from approximately 500 ppm to 2500 ppm. Other SRM's currently under development are NO_2 in air at concentrations ranging from 250 ppm to 2500 ppm; oxygen in nitrogen and hydrogen sulfide in a hydrocarbon gas blend. These SRM's are applicable to the testing of methods for measuring source concentrations of pollutants. Standards are also being developed for ambient air monitoring. Three SRM's consisting of carbon monoxide in air (to complement the existing carbon monoxide in nitrogen SRM's) at concentrations of 9.5 ppm, 18.0 ppm and 42.7 ppm have been completed. Gas blends of SO_2 and NO_2 in nitrogen at ppb concentrations are presently being investigated as alternatives to the NBS permeation tubes for ambient air monitoring.

Recognizing that particulates may be the most serious pollutants in regard to long term chronic health effects, several projects are underway in particulate metrology. Because X-ray fluorescence analysis provides a rapid method for the analysis of the elemental composition of particulates collected on filter papers and impactors, potential SRM's for the calibration of X-ray fluorescence instruments are being investigated. Test samples have been prepared by thermally evaporating thin metallic films onto polycarbonate filters. Test samples have also been prepared by sputtering glasses containing known quantities of trace elements with an argon ion beam onto polycarbonate filters. Both of these methods of preparation are attractive because of the ruggedness of the prepared samples. Yet another approach is the manufacture of glass microbeads from a well characterized bulk glass. The microbeads are intended to simulate real particulates but their composition and size can be controlled so that a series of standards of varying size and composition could be prepared. In all three approaches, samples have been successfully prepared and methods for performing certification analyses (necessary for the certification of the SRM) are being developed.

Two measurement methods have been developed for particulate monitoring. The first is an instrument for measuring the size distribution of particles of known density. The principle of operation is the relation between the Doppler shift of laser light scattered from a moving particle in a gravitational field and the mass of the particle. The primary use of such an instrument will be to characterize aerosol generators which are used to calibrate other particulate sizing equipment. The instrument has been built and has been demonstrated to have a size resolution of 0.05 micrometers at a particle size of 6 micrometers and an accuracy of 1% in determining the size of a 6 micrometer particle. The ultimate range of the instrument now appears to be 0.5 micrometers to 20 micrometers. Accuracy and resolution over this entire range are yet to be tested.

The second instrument developed is for the measurement of sulfur in particulate matter. The principle of operation is the combination of an electrostatic precipitator with a flame photometric detector specific for sulfur. The electrosatatic precipitator is turned on and off rapidly, thus developing an AC signal in the flame photometric detector corresponding to the amount of sulfur contained in the particles captured by the precipitator. The instrument has been field tested and the detection limit so far achieved is 2 micrograms per cubic meter. However, problems of systematic errors introduced by a background of sulfur dioxide and long response times (on the order of a minute) need to be solved.

A method to distinguish the sulfur compounds in particles by thermally evaporating the compounds is presently being investigated. Different compounds vaporize at different temperatures and it may be possible to use this technique to differentiate between the different compounds.

Finally, work is underway to provide SRM's for elemental analysis of fuels and raw materials. Samples of Western and Eastern coal have been prepared. Homogeneity tests on the Western coal have been completed. Both coals will eventually be certified for their trace element composition. Two oil shale materials have been prepared for possible certification but work on these materials has been suspended pending re-evaluation of the potential of oil shale development.

This has been a very brief summary of work in progress in the development of measurement standards for air pollution monitoring as part of the Interagency Energy/Environment R&D Program. Details of the work are described in semiannual reports from NBS to the EPA Office of Energy, Minerals and Industry.

ENERGY-RELATED RESEARCH IN AIR MONITORING METHODS

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INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is committed to the protection of the worker from harmful materials and conditions in the working environment. The Measurements Research Program in the Measurements Research Branch aids in accomplishing this goal by investigating methods and instrumentation used to collect and measure harmful chemical and physical agents in the workplace air. Three different levels of methods and instrumentation are used to effectively monitor the workplace air: personal monitors, survey instruments, and area monitors.

The Federal Occupational Safety and Health Standards[1] require the determination of worker exposure to air contaminants. The exposure is determined at ceiling levels or at 8-hour, time-weighted average levels. Industrial hygiene practice over the years has indicated that the optimum method for determining exposure is to obtain breathing zone samples which can be analyzed for specific contaminants. The breathing zone is an area near the worker's face that contains air that is representative of air inhaled by the worker. To obtain these personal samples, sampling systems have been devised that consist of a light-weight, self-contained pump, and a sampling head that contains an efficient collection medium for the specific type of air contaminant of concern. The sampling head is attached to the worker's clothing within the breathing zone. Air is drawn through the sampling medium at a measured rate and for a measured length of time. The sampling medium is then sent to an analytical laboratory for analysis to determine the worker exposure. The sampling medium typically consists of a filter for particulates and a solid sorbent tube or liquid sorbent systems (impinger or bubbler) for gases, vapors, and particulates.

To assess areas of contamination in the workplace, it is very useful to have portable survey instrumentation that is light-weight, accurate, agent-specific, and capable of rapid measurement of contaminant levels. These survey instruments are used by Occupational Safety and Health Administration (OSHA) inspectors to pinpoint areas of possible noncompliance for further investigation; by the employer to monitor contaminant levels and target areas to be subjected to engineering controls; and by NIOSH to evaluate problem areas, bearing on the accuracy and collection of epidemiological data, and the effectiveness of personal sampling methods.

The third monitoring method is area monitoring. This includes less portable instrumentation that has continuous monitoring and recording capabilities to determine contaminant level variation at any time over an extended period of time at a given location. Additional possibilities for such monitors include triggering warning devices in case of dangerous contaminant levels and activating engineering and process controls that may be used to keep contaminant levels below the prescribed threshold.

The increased emphasis on energy technology in recent years has impacted on the occupational health area by increasing, in many instances, the number and concentration of air contaminant numbers. For this reason, versatile and specific multiagent monitoring systems have been one of the goals under this program.

Another impact is in energy conservation where insulating materials such as asbestos and fibrous glass and other fibrous minerals play an important role. Exposures to these fibrous materials have traditionally been measured by sample collection of filters and subsequent analysis by manual counting of individual fibers.[2] Improvements in the precision and speed with which these measurements can be made has been another goal under this program.

TECHNICAL DISCUSSION

The six projects that are underway in this interagency program include:

(1) Evaluation of Personal Sampling Devices in Cold Environments

(2) Development of a Fibrous Aerosol Survey Monitor

(3) Development of a Miniature Gas Chromatograph

(4) Development of a Portable Microwave Spectrometric Analyzer

(5) Development of a Personal Filter Sample Fiber Counter; and

(6) Development of a Personal Sampling and Analytical Method for H_2S.

These projects are in various stages of completion and the results indicated to date are described below:

Project 1

The evaluation of reliability of sampling devices in cold environments has been carried out under NIOSH contract by Research Triangle Institute and is nearly complete. The investigation has yielded information on the physical limitations to commercially available battery operated, personal sampling pumps being used at low temperatures. The testing protocol included temperatures from 25°C to -50°C. Various aspects of pump operation were considered, including battery type, lubricant properties, physical damage, and service life. Preliminary evaluations of the data indicate that the primary limitations of the pumps are due to battery characteristics. The typically used rechargeable nickel/cadmium batteries can supply power to the pumps adequately down to -20^{0}C. Alkali cells have a similar temperature limitation. Some pumps contain a mercury reference cell in addition to the nickel/cadmium batteries to improve the time dependent flow characteristics. The mercury cells suffer breakdown at -10^{0}C. Virtually all of the pumps operated successfully down to -50^{0}C when an external power supply was employed. Subsequent operation of these same pumps at room temperatures indicated that there was no significant wear or change in the normal operating characteristics.

Project 2

The development of a fibrous aerosol monitor by the GCA Corporation under NIOSH contract has proceeded satisfactorily and is in the final stages of instrument testing. The prototype instrument is a completely portable, battery operated device with a volume of 1.5 cubic feet (0.04 cubic meters) and a weight of approximately 30 lbs (14 kg). The instrument detects and counts individual aerosol fibers in real time and gives an indication of concentration in fibers/cm^3 averaged over periods of 1, 10, 100, and 1000 minutes. The principle of detection involves alignment of the fibers by an electrostatic field and detection of the fibers by light scattering from a HeNe laser beam. The alignment process effectively discriminates against non-fibrous particles. The light scattering signal gives information that is indirectly related to fiber dimensions. Therefore, calibration against the light microscopy method is necessary.

The instrument will undergo further field and laboratory testing to determine its full capabilities and limitations. The initial goal of testing is to ensure that the instrument will count fibers in a manner and sensitivity that is the equivalent of the method required by the Federal standard for asbestos, namely, the filter collection/light microscopy counting technique. Beyond this phase of the investigation, the fibrous aerosol monitor shows potential for more detailed investigation of the epidemiology of exposure to asbestos and other fibrous aerosols, because it gives more precise and rapid fiber concentration data and it has fiber sizing potential as well.

Project 3

Increased versatility and capability in monitoring the workplace air for various gaseous contaminants has been one of the goals in this project. The miniaturization of a gas chromatograph to the point where it is not much larger than a pocket calculator has been studied by Stanford University Electronics Laboratory under NIOSH contract. Capillary GC columns of 0.5 to 3 meters long have been fabricated on the surface of a silicon wafer about 4 cm square. Column linings such as polyethylene glycol and Apiezon L have been coated onto the 20 μm x 200 μm cross-section column. Investigations of various detectors and gas handling valves that are mounted on the source silicon wafer have also been made. Currently, the most compatible detector seems to be a custom made miniature thermistor detector. This detector promises to give a sensitivity on the order of 50 ppm. Both pneumatic and solenoid valves have been constructed. The pneumatically operated valves require bulky, external gas sources and excessive power, which is incompatible with the final design concept. Miniature solenoid valves have been constructed that have acceptable performance. Because of the very high tolerances and fast valve action required, the success rate in valve construction has not been very high and this has limited the number of complete systems available for testing.

Software for microcomputer control of the entire GC is being investigated. Relatively simple algorithms will be developed for data extraction and for compensation for external variables such as temperature and pressure. The development is progressing satisfactorily and the entire concept looks promising. Previous versions of this GC have produced chromatograms with good separation of a mixture of isobutanol, acetone, and ethanol in one minute at room temperature with a column flow rate of 1 μl/sec and a 25 nl sample volume.[3]

Project 4

Lack of specificity has been a common problem with many monitoring instruments. For this reason, and to provide multiagent capability in an air monitoring instrument, a microwave spectrometric analyzer is being developed at the Lawrence Livermore Laboratory. Microwave spectroscopy provides very high specificity with minimum likelihood of interferences. To increase the sensitivity of the instrument, semipermeable membranes will be used to enhance the concentration of polar compounds in the detection cell. The instrument will be set up to measure the concentrations of ten compounds at concentrations one fifth the Federal standard for workplace air. The compounds to be measured include:

acetonitrile
acetaldehyde
acetone
carbonyl sulfide
ethanol
ethylene oxide
iso-propanol
methanol
propylene oxide
sulfur dioxide

Previous versions of the microwave spectrometric analyzer have been built for single contaminants including formaldehyde and ammonia. The present instrument will be capable of being switched to any of the above compounds. Because of high power and vacuum requirements, the instrument will be operated on AC line power, but will be sufficiently portable for evaluation of various areas during field evaluation of air contaminants.

Project 5

In addition to survey measurement of exposure to asbestos and other fibrous aerosols, it is necessary to measure time-weighted average personal exposures in order to comply with the Federal standard for asbestos.[2] To accomplish this, an automated fiber counter is to be constructed that will be capable of providing rapid and precise evaluation of fiber concentrations collected on filters. The present procedure for determining exposure to asbestos involves filter collection of personal samples of air to which the worker is exposed, and analysis of the filter samples by light microscopy. The optical counting of these filter samples is tedious and yields air concentration estimates of relatively poor precision primarily because of the limitations of human counters. The automation of this procedure will free up technical expertise for other laboratory procedures and improve the reliability of the exposure measurements. Light scattering from fibers produces distinctive patterns which can be analyzed by instrumental means. These scattering patterns will be the basis on which the instrument will be developed.

Project 6

The current NIOSH recommended method for personal sampling of H_2S utilizes collection by midget impinger and colorimetric analysis. The midget impinger is an undesirable device to use as a personal sampler because of its size and its glass construction. The liquid sorbent material is prone to spillage and contamination in the field. A number of solid sorbent materials are being investigated for their use in a collection device for H_2S. The ideal sorbent material would have: 1) 100% collection efficiency; 2) 100% desorption capability for analysis; 3) low susceptibility to humidity effects; 4) minimal collection of interfering analytes; and 5) no storage losses of collected samples.

PROJECTIONS

The instruments and methods presently being developed under NIOSH direction will need to undergo laboratory and field testing to determine their utility as industrial hygiene tools. The miniature gas chromatograph will require more development and investigation before a field usable prototype can be constructed and evaluated.

Apart from the specific projects that have been discussed, the general goals under the present NIOSH program are to: 1) achieve expanded versatility in coping with the wide range of organic compounds simultaneously present in industries closely tied to energy production, and 2) to provide improved measurement capability for specific compounds important in energy intensive industries.

INTERAGENCY PARTICIPATION

The majority of the energy related research in the Measurements Research Program is being funded through interagency agreement allocations from EPA. The fibrous aerosol monitor development is partially funded by the Bureau of Mines. NIOSH is providing one man-year of effort during FY-77 for this energy related research.

REFERENCES

1. Department of Labor, Occupational Safety and Health Standards, 29 CFR 1910.1000, Federal Register, January 1, 1976.

2. Ibid, 1910.1001.

3. Terry, S.C., "A Gas Chromatography System Fabricated on a Silicon Wafer Using Integrated Circuit Technology." NASA Technical Report No. 4603-1 (1975).

CHARACTERIZATION, MEASUREMENT, AND MONITORING PROGRAM

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INTRODUCTION

The Division of Biomedical and Environmental Research's (BER) analytical characterization program is conducted in association with several high priority energy technology process developments. The objective is to provide information on potentially troublesome effluents or emissions which would be useful in guiding control technology considerations and which is needed in order to develop a comprehensive assessment of environment and health effects. This program includes, when required, preoperational baseline studies on the natural levels of elemental, chemical, particulate and other potential pollutants prior to start-up of a specific energy technology process. Proceeding to the operational activities, a sample collection and field measurement program is conducted to identify effluents or emissions characteristic of the specific operational facility.

An important aspect of this program is the preparation of selected material fractions which are provided to appropriate biological testing groups for screening studies. It is important to underscore this interrelationship. The sampling and characterization program is not an isolated activity but operates as an integral component of a comprehensive environmental and biomedical program.

BER's measurement and monitoring research program is concerned with the development of improved instrumentation, methodology and procedures for the detection of energy technology-related pollutants and the determination of exposure to these insults. This activity ranges from preliminary investigations into new concepts and novel approaches for measurement, through development of laboratory units in order to demonstrate feasibility, to field evaluation of prototype systems to determine performance capability.

The relationship of this measurement program to other aspects of energy development is depicted schematically in Figure 1. In this figure, programs dedicated to the development of individual energy technologies, such as coal conversion, geothermal, oil shale, etc., are shown at the top. Studies to establish the environmental and health impacts of the energy technologies are shown as circles. These include the programs of effluent characterization, evaluation of harmful effects of effluent components, investigation of atmospheric, aquatic and terrestrial transport mechanisms of pollutants, etc. The success of these programs depends critically on the ability to make measurements on a wide variety of parameters. Thus, the availability of adequate instrumentation to make these measurements is essential. Some of the instrumentation needed for these programs already exists and is commercially available. Some of it

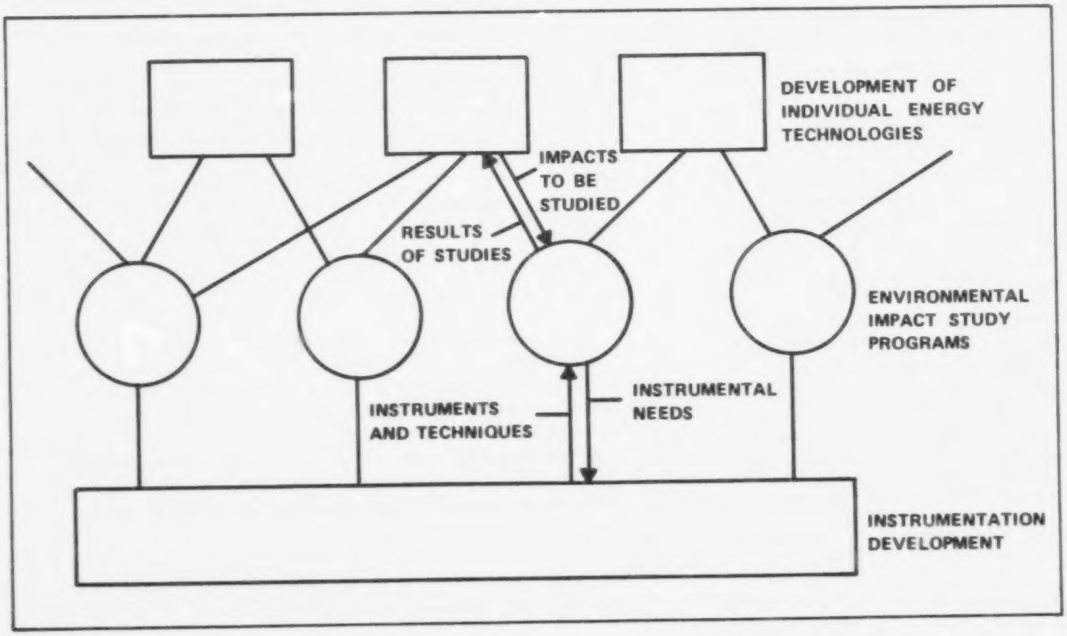
DEVELOPMENT OF INDIVIDUAL ENERGY TECHNOLOGIES
IMPACTS TO BE STUDIED
RESULTS OF STUDIES
ENVIRONMENTAL IMPACT STUDY PROGRAMS
INSTRUMENTS AND TECHNIQUES
INSTRUMENTAL NEEDS
INSTRUMENTATION DEVELOPMENT

Figure 1.

Illustrating the hierarchy of support functions that relates instrumentation development to the development of energy technologies.

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is now under development in the instrumentation laboratory and will become available to the scientific community. In other cases, the need for new forces of instrumentation is now being recognized. Some essential measurement programs cannot be completed until new types of instrumentation are developed.

The role of the Measurement Technology program, as depicted in Figure 1, is to facilitate the energy impact study programs by developing the necessary, but presently unavailable, measurement tools.

The specific projects within this program category, which are supported through the Interagency Energy/Environment R&D Program, are discussed in detail below.

DISCUSSION

Optical Absorption Properties of Sulfate Aerosols--P. Cunningham, Argonne National Laboratory

The Chemical Engineering Division at Argonne National Laboratory (ANL) has developed methods for the chemical characterization and analysis of airborne particulate material as a function of particulate size and time. This technique, which is based on the infrared spectroscopic analysis of particulate samples, has been used to show that there are, indeed, significant variations in the chemistry of airborne particulate with size and that within a specific size range the chemistry changes with time. Of particular significance has been the identification of ammonium sulfate as the predominant constituent of submicrometer particles and the observation that the degree of acidity of this sulfate is highly variable with time. This work has been directed toward the further development of the infrared spectroscopic method and toward more detailed characterization and analysis of atmospheric neutral and acidic sulfates.

Airborne particulate matter is commonly collected by a wide variety of filtration and impaction methods, each having its advantages and disadvantages. To supply samples for analysis by infrared spectroscopy, sample collection with a Lundgren impactor facilitated sample handling and supplied the necessary time- and size-resolution. The use of the impaction principle, however, limited the sample to particles above ca. 0.1 μm in diameter. A procedure has now been developed which quantitatively recovers water soluble sulfate from filter samples while maintaining the acidity of the sample. The procedure, although specifically developed to prevent neutralization of acidic sulfate, may also minimize other chemical modifications during extraction.

The filter extraction procedure starts with the extraction of the water-soluble material from the filter by ultrasonic agitation of the filter with distilled, CO_2-free water. The filter is removed, a weighed amount of potassium bromide is dissolved in the extract, and the solution is immediately frozen. The sample is freeze-dried and a pellet pressed in the standard way for subsequent infrared spectroscopic examination. The acidity of the sulfate is maintained throughout the procedure without any neutralization or reaction with the KBr.

During August and September of 1975, a field comparison study was conducted in the St. Louis region in coordination with the Environmental Protection Agency (EPA). The ANL samples were collected with time- and size-resolution using Lundgren impactors simultaneously with the samples collected by the EPA and by other participants.

The EPA samples were collected using a dichotomous sampler which divides the particles into fine (less than 3.5 μm) and coarse (greater that 3.5 μm) size fractions. Each fraction is collected on a separate 37mm Fluoropore (Teflon) filter. A set of thirty filters was received from the EPA and included samples from both size fractions.

Appreciable sulfate was found only on state IV of the Lundgren impactor, and on the fine filter of the dichotomous sampler. The stage IV samples (nominal 50% cut point of 0.3 μm diameter) had a greater percent sulfate concentration in the particles collected than the filters; however, the filters had greater total sulfate (expressed as $\mu g/m^3$ of air) than did the impactor samples. This indicates that sulfates are more concentrated in the size fraction $\sim$ 0.3 to 1 μm, than in the overall aerosol, but that there are also significant quantities of sulfates in particles below $\sim$ 0.3 μm in diameter. These results are consistent with current concepts of particulate matter in the air.

In addition to the infrared method developed at ANL, light scattering techniques developed at the University of Washington, Seattle, and Washington University, St. Louis, permit time-resolved (1-hr) detection of acidic sulfate aerosol. The three methods make use of quite different physical characteristics of the particles. A side-by-side comparison of these procedures was made in a two-week field study at Tyson, Missouri. Time- and size-resolved samples were collected continuously using the Lundgren impactor, with concurrent aerosol analysis by the light scattering techniques. Good agreement was found in the results from the three techniques.

A new method is being investigated for the measurement of the acidity of a particulate sample collected on a filter. The new method is based on an indirect measurement of the acidic hydrogen in the sample by means of an acid-specific vapor-phase reagent of suitable characteristics. The compound resulting from the titration is then measured to determine the acidity of the sample on the filter.

Sulfate Emissions from Fossil Fueled Combustion Sources--L. Newman, Brookhaven National Laboratory

The purpose of this study is to determine the primary emissions of sulfate species from various types of fossil fueled combustion sources and relate the magnitude of these emissions to variables affecting the combustion and emission control processes.

Flue gas composition was shown to consist of primarily N_2 (71 to 75%), CO_2 (12 to 13%), water (9 to 15%), excess O_2 (1 to 4%), and SO_2 (250 to 1500 ppm). The sampling technique must not only determine the oxides of sulfur but also several of the other constituents (e.g., water and O_2) in order to verify that representative samples are being quantitatively obtained and analyzed.

Both of the principal sulfuric acid sampling techniques - controlled condensation and isopropyl alcohol impinger collection - were described and the experiences of other investigators with these methods were discussed.

Theoretical aspects governing the formation and collection of sulfuric acid aerosol were considered. In typical flue gas, acid particulate size during the removal process in a condensation coil was estimated to be between 1.1 to 1.6 μm when water vapor content varies between 9 to 15% by volume. A 20-turn condensation coil was calculated to have better than 90% efficiency for removal of acid aerosol at flue gas sampling rates from 5 to greater than 20 ℓ/min.

Apparatus for the controlled condensation technique was designed and fabricated. Basically the equipment consisted of an acid aerosol condensation coil and glass wool plug maintained at 140°F followed by an ice water cooled water vapor condenser and collector for quantitative determination of flue gas water content. This was followed by an evacuated bottle for O_2 and CO measurements and then H_2O_2 impingers for collection of SO_2.

Preliminary results with laboratory tests showed excellent recovery of added water vapor ranging from 84 to 107% with an overall average recovery of 96%. For sulfuric acid, when the entire sampling apparatus from the probe to the water condensate was checked for acid, recoveries ranged from 64 to 74%. Losses are suspected to have occurred in the sulfuric acid volatilizer and are not related to the efficiency of the collection apparatus.

Two field runs were performed at a 380 MW power plant unit. In the second run, recovery of both water vapor (10.25%) and sulfur dioxide (1336 ppm) was within 1% of the expected concentrations, 10.35% H_2O and 1332 ppm SO_2, respectively, based on fuel composition and furnace excess oxygen.

Detailed laboratory tests and field experiments with the controlled condensation technique will continue in the next report period. Preparation for similar evaluation of the isopropyl alcohol methods, EPA Methods 6 and 8, is underway.

Beta Guage and XRF Analysis for Aerosol Sampling Studies--F. S. Goulding, Lawrence Berkeley Laboratory

Development of an Elemental Sulfur Monitor. The current activities represent the final stages of a two year research and development program. The first prototype sulfur monitor is in the final stages of construction and should be available for field testing by May 1, 1977. Following these tests final modifications will be made and a prototype will be delivered to EPA for their evaluation.

β-Guage Development. We have previously demonstrated the use of the β-particle attenuation method for the large scale measurement of total particulate mass of samples collected on membrane filters. Our present program involves the development of a β-guage system using a room temperature Si(Li) detector and a microprocessor for data acquisition and reduction. The detector for the proposed system has been fabricated and tested. It is now being integrated into the complete electronic/mechanical setup for more detailed evaluation. The mechanical hardware for the automatic sample handling has been constructed. The microprocessor controller will be similar to the one used for the Sulfur Monitor and thus awaits the completion of that project before proceeding.

Consultation on the Design of an Air Sampler. Our contributions to the development of an improved dichotomous sampler will be in the areas of defining the design parameters of the air inlets and evaluating the final instrument when it becomes available from the EPA subcontractor. We will then test the final instrument to ensure that the goals have been realized.

Development of Ultra Sensitive Ammonia Monitor--L. W. Hrubesh, C. J. Morris and V. C. Barton, Lawrence Livermore Laboratory

Our objective of this project is to determine a satisfactory method for extending the sensitivity of a microwave ammonia monitor by preconcentration. This study is to result in the selection of a preconcentration method which can satisfy the following requirements: 1) Extend the detection limit of microwave instrumentation to 1 part per billion in air; 2) Operate in an automatic mode; and 3) Be field usable.

Prior work has shown that a chomatographic packing material, chromosorb 104, is useful as an efficient trapping material for ammonia with an additional property of liberating the trapped gas at a modest temperature. Our following work has been to determine the quantitative reproducability of the trapping and heating cycle at sub-part-per million levels of ammonia in air, and to determine the operating characteristics of the trap in combination with the microwave ammonia monitor for reliable measurements of ammonia in the measurements of ammonia in the 1 to 10 part per billion concentration range. Laboratory tests have demonstrated reproducible detectability within that range for a trapping greater than 15 minutes. We have also established calibration procedures for the instrument during this time period.

Our next objective is to field test this instrumentation. Arrangements are being made to include this instrumentation in a mobile unit which will be based in the Imperial Valley of Southern California. During the remainder of the FY 1977 we will be evaluating the microwave/preconcentrator combination in actual field operation. We will prepare a summary report, detailing the enzyme study and its results by October 1977.

Our studies have disclosed two problem areas associated with this technique for ammonia monitoring; a short usable lifetime of trapping material for reproducible low level detection, and effects of water vapor during the measurement.

We have found that the trapping capacity of the chromosorb material changes slightly with each successive cycle. The capacity changes are more pronounced when higher flashing temperatures are used. Since a high temperature (~140°C) is required to efficiently drive-off the trapped ammonia, the usable trap lifetime is considerably reduced. We have found it necessary to change the trap material after each full day of operation. Unfortunately, each change of trap material requires recalibration. This is a definite limitation of the technique for long term ambient monitoring.

Water vapor has been found to effectively displace ammonia that is chemically or physically absorbed on surfaces. For example, surfaces of teflon tubing used to deliver samples to the trap absorb ammonia molecules which eventually passivate the surface against further absorption. When a carrier with as little as 0.01% water vapor is used to flush the tubing, much of the trapped ammonia is liberated and is readily detected by the microwave instrument. Since the effect manifests itself as changes in measured ammonia due to changes in humidity for ambient monitoring, it is a potential problem for using this or any similar technique for air monitoring low levels of ammonia vapor.

Our field studies will determine the effects of these limitations in actual ambient monitoring conditions. We will be comparing our measurements with wet chemical ammonia analysis.

Optimize Filters and Stack Probe for Aerosol Source Sampling--J. C. Elder, M. I. Tillery, Los Alamos Scientific Laboratory

This EPA/BER program to evaluate the present EPA particulate sampling method (Method 5) and develop improved methods of extracting particulate samples from stacks has been in progress for approximagely 18 months. Since the last letter annual report to EPA in June 1976, experimental activities have been directed primarily at evaluation of glass fiber sampling filters operated at 120°C and 10.3 cm/s air velocity. The filters were tested against monodisperse dye aerosols, generated by a vibrating orifice aerosol generator, in the size range 0.6 to 4.4 μm geometric diameter (D_p) dioctyl phthalate aerosol. The 1106 BH and GF/A are commonly supplied with commercial stack sampling use. Physical characteristics of these four filters are similar, varying only in the range of fiber sizes and filter thicknesses.

Efficiency of all four filters at 120°C and 10.3 cm/s exceeded 99/9% for particle sizes above 1.0 μm (D_p). The smallest particle size (0.6μm) was collected with poorer efficiency, generally between 99.6 and 99.8%. A decreasing collection by impaction, but as other studies have shown, efficiency of fibrous filters does reach a minimum and increases again as the diffusion mechanism of collection becomes effective in collecting particles near 0.1 μm. Further testing with smaller aerosols is in progress to assure that the minimum efficiency does not fall below acceptable limits. These tests utilize polydisperse dye aerosols generated in the range 0.07 to 0.2 m (D_p) from compressed air nebulizers.

Efficiencies of these filters operated at half-flow (5.2 cm/s and 120°C were greater than 99.8% for aerosols larger than 1 μm and between 99.4 and 99.7% for the 0.6 μm aerosol. Significant difference between half-flow and full-flow results was not noted.

Results of the program will be presented in June 1977 at the Air Pollution Control Association annual meeting in Toronto, Canada. The paper is entitled, "Evaluation of EPA Method 5 Probe Deposition and Filter Media Efficiency." A formal report is being prepared and should be published before the end of FY 1977. This report will cover our quantitation of probe deposition losses (summarized in our June 1976, letter report to EPA) and the filter efficiency studies briefly summarized in this letter.

Following discussions with EPA representatives at Research Triangle Park, North Carolina, program direction has been changed from development of a multistage size classifying sampler to an improved extractive sampler capable of determining total suspended particulate with less expense than the Method 5 sampler, greater accuracy, physically greater convenience, and less susceptability to formation of so-called "false" particulate. We will design, construct, and test a prototype particulate sampling train with features differing from the existing Method 6 train as follows: (1) higher sampling flow (above 100ℓ/min); (2) electronic flow and moisture content instrumentation; (3) in-stack filter for low-moisture conditions (existing out-of-stack filter would be retained for high-moisture conditions), and (4) reduction of cation sources within the train which lead to formation of "false" particulates. Although the train will not be designed for stack temperatures above approximately 320°C, which may limit its universality somewhat, it will be applicable to a wide variety of particulate sources. This program change is aimed at satisfying the current priorities indicated by EPA.

Development of Instrumentation and Methods for Characterizing Aqueous Effluents from Oil Shale, Oil Refining and Geothermal Sources--B. R. Clark and M. R. Guerin, Oak Ridge National Laboratory

In the course of developing methods for characterizing the aqueous effluents from various energy technologies, we chose to emphasize methods of rapid analyses for chemical classes of organic components and the development of bioassay methods for evaluating aqueous wastes for biological activities. Since a number of good methods already exist for the characterization of inorganic components in aqueous samples, we have limited the research activity in this area to the application of analytical techniques which are available for routine analysis, e.g., spark source mass spectrometry.

A review of the literature dealing with the analysis of organic substances in water leads one quickly to the conclusion that no general method is available which can be applied to total content. All preconcentration steps, i.e., freeze drying, adsorption or solvent extraction methods, are selective toward certain compound types. We decided that a reasonable approach to the chemical characterization of organics was to develop some simple, reasonably direct methods for analyses of specific compound class type since this is the greatest concern when looking at possible health and/or environmental hazards in the effluents. This approach, in conjunction with bioassay screening, provides a rather economical route to the characterization and evaluation of effluents compared to exhaustive chemical analyses. Early work in this project area involved some detailed characterization of a by-product water from oil shale retorting. This material was used to evaluate the compound type selectives of several different adsorption and extraction methods. Polar compounds are not easily analyzed using any of the standard methods and there are serious difficulties with quantitation. To circumvent this problem to some extent, we developed a gas chromatographic method to analyze these effluents for polar compounds using direct injection of aqueous samples onto a Tenax-GC packed column. This method is rapid and gives quantitative results for major polar components. Minor components are detectable down to about 1ppm. Table 1 shows

		Concentration (μg/ml)		
Peak	Compound	Oil Shale Retorting	Synthane Coal Gasification	COED Coal Liquefaction
1	acetic acid	600	620	600
2	propanoic acid	210	60	90
3	n-butanoic acid	130	20	40
4	acetamide	230	--	--
5	n-pentanoic acid	200	10	30
6	propionamide	50	--	--
7	n-hexanoic acid	250	20	30
8	butyramide	10	--	--
9	phenol	10	2100	2100
10	n-heptanoic acid	260	--	--
11	o-cresol	30	670	650
12	m & p-cresols	20	1800	1800
13	n-octanoic acid	250	--	--
14	2,6-dimethyphenol	--	40	30
15	o-ethylphenol	--	30	30
16	2,5-dimethylphenol	--	250	220
17	3,5-dimethylphenol	--	230	240
18	2,3-dimethylphenol	--	30	30
19	n-nonanoic acid	100	--	--
20	3,4-dimethylphenol	--	100	900
21	n-decanoic acid	50	--	--
22	α-naphthol	--	10	--
23	β-naphthol	--	30	--

TABLE 1.

ORGANIC COMPOUNDS DETERMINED IN BY-PRODUCT WATERS FROM FOSSIL FUEL CONVERSION PROCESSES data for shale oil-by-product water and two coal conversion by-product waters. Note the homologous series of carboxylic acids in the shale oil by-product water. Also, note the large phenolic content of the coal waters. Non-polar components offer less difficulty and can be analyzed as aliphatic or aromatic classes with minimal effort. We have developed a simple, direct method for aliphatics and have applied that to aqueous effluents from shale oil retorting, petroleum refining, coal conversion and a geothermal brine. The method is a solvent extraction with benzene or hexanes followed by an alumina column elution step. A method was also developed for the direct isolation of polycyclic aromatic hydrocarbons (PAH) and data have been obtained on shale oil and coal conversion by-product, aqueous effluents.

Perhaps the most important part of this project revolves around the development and incorporation of bioassay techniques into the characterization scheme. Application of the Ames mutagenicity test (L. L. Epler, Biology Division, work partially sponsored by EPA-ERDA "Pass-Thru") to aqueous systems of this sort is quite new and has, thus far, provided a valuable complement to chemical data. Effluents have been tested in whole and as chemical class subfractions generated by an acid-base-neutral fractionation scheme. This has pointed to biological activities in certain fractions which implicate specific compound classes, e.g., ether soluble bases in shale oil by-product water. The earlier work with this material has led to broader application to a number of aqueous effluents, including several coal conversion effluents. In addition to mutagenesis testing, acute toxicity studies have been performed by members of the Biology Division, using other biota.

Currently, we are engaged in the characterization of petroleum refining effluents with respect to PAH and aliphatic hydrocarbon content. We are also pursuing liquid chromatographic methods for analyzing amines in aqueous samples. The use of radio-immunoassay procedures for specific samples offers an interesting possibility and is being investigated.

Instrumentation and Methods to Identify, Measure and Analyze Energy-Related Aerosols and Particulates in Relation to their Direct Effects on Health--R. L. Carpenter, Inhalation Toxicology Research Institute/Lovelace Biomedical and Environmental Research Institute

This project is directed toward improving the methods available for chemical and physical characterization of aerosols from processes utilizing fossil fuels, particularly coal. Virtual aerosol impactors are being designed and tested to provide improved instrumentation for obtaining size selective aerosol samples from these sources. Work is also underway to couple analytical instruments to the impactors to provide methods for in situ chemical analysis of samples. Methods for identification and quantitation of potential toxic organic emissions are being developed as are in vitro methods to predict the solubility of particles in the lung following inhalation.

Recent developments have made the design of reliable, low-loss laboratory aerosol impactors relatively straightforward. However, the adaptation of these devices for use in field studies has not been well developed. The need still exists for size-selective samplers which operate at high temperatures and pressures, sample gas streams whose composition differs from air, and can sample high volumes. Virtual impactors offer several advantages which make them potentially useful in these situations. Virtual impactors can collect large samples which may be brought out of the impactor without opening it, thus providing a capability for process stream sampling at high temperatures and pressures. A prototype round-jet virtual impactor has been constructed and is undergoing laboratory and field tests. The device consists of five stages and a final filter. It will collect particles from 0.3 to 10 μ in aerodynamic diameter. Samples may be either internally or externally collected. Two prototype slit-jet virtual samplers have been constructed and are currently being studied to ascertain their operation characteristics. These may be designed to sample at a wide range of flows. It is anticipated that the same basic design will suffice for both high and low volume samplers.

The capability of virtual impactors to present a sample external to the impactor offers the possibility of in situ sample analysis. Initial efforts are centered on combining photo-ionization and flame ionization detectors with virtual impactors. The resulting instruments may be used to detect organic species as a function of particle size.

Methods to identify and quantitate organic compounds, particularly polynuclear aromatic hydrocarbons, are of great interest. Recent studies at the Inhalation Toxicology Research Institute have concentrated on using extraction techniques followed by high performance liquid chromatography (HPLC) to identify organic materials. These studies are using the HPLC in a stopped-flow mode and analyzing eluted peaks using a spectrofluorimeter as a detector. In this mode, a fluorescent spectrum of each material in a mixture is obtained. Results show that, for example, mixtures of napthalene, anthracene, chrysene and triphenylbenzene may be separated and identified.

Additional studies of methods for organic materials found in coal combustion have employed gas chromatography alone and in combination with mass spectroscopy. Techniques have been developed to separate organic materials derived from coal and ash by either extraction or by pryolysis.

Fly ash samples from coal combustion are being evaluated, in vitro, to predict their solubility in the lung following inhalation. Using dissolution cells, the solubility of field-collected materials is being determined. Analysis of organic materials is being carried out by the methods described earlier. Neutron activation of the samples prior to the start of solubility studies provides an analytical method for a number of elements. In *vitro* solubility half-times are being determined for the composite ash material as well as for selected elements.

Instrumentation and Methods--V. A. Fassel, Ames Laboratory

Instrumentation and Methods for Oil Shale Related Effluents and Oil Refining Related Effluents. The broad objectives of these studies are to develop the basic sciences, the investigative methods, and the hardware so that the demanding analytical requirements associated with the characterization and quantitations of heavy weight organic pollutants in effluents from oil shale and oil refining operatings can be met in a viable practical manner. Special attention is being placed on the class of compounds known as polynuclear aromatic hydrocarbons, many of which are known carcinogens. The specific thrusts of the present studies are to identify the ambiguities in the analytical results obtained by various analysts when activated carbon or macroreticular resins are employed to isolate the organic compounds from the water sample. The experimental approach is based on comparing critically the sorption and desorption characteristics of the two isolation schemes on the same samples of aqueous effluents.

Sorption and recovery (S and R) efficiency comparisons of activated carbon (Calgon filter sorb 400) and macroreticular resin (Rohm and Haas XAD-2) for one hundred model organic compounds added to water at the 100 μg/l and 13 compounds added at the one μg/l levels have been completed. The classes of compounds tested included alkanes, esters, alcohols, phenols, chlorinated alkanes and alkenes, aromatic compounds, chlorinated aromatic compounds, aldehydes, ketones, amines, carboxylic acid, sulfonic acids, pesticides and flame retardants. The S and R efficiency of the XAD-2 resin is clearly superior to that of carbon for esters, alcohols, phenols, aromatic compounds, chlorinated aromatic compounds, aldehydes, ketones, amines and pesticides, whereas carbon is marginally superior in the case of chlorinated alkanes and alkenes. In the cases of alkanes and carboxylic acids, neither sorbent is very effective. It is clear however that both resin and carbon are quite effective sorbents but recovery of sorbed compounds from carbon is difficult and inefficient. Better recovery methods for releasing sorbed compounds from carbon need to be developed. Of the two sorbents, it is clearly easier to clean up the resin, thereby achieving a lower blank for analytical applications.

A combined Carbon-Resin Organic Compound Accumulator (CROCA) is now ready for testing at oil shales or oil refinery field conditions. Analytical characterization of the accumulated organic compounds will be performed in the Ames Laboratory.

Instrumentation and Methods for Geothermal Source Related Effluents. The broad objectives of this study are to develop the basic science, the investigative methods, and the hardware so that trace elemental impurities occurring in geothermal effluents and brines can be determined quantitatively, simultaneously, and with adequate sensitivity. One of the most attractive techniques for performing the analyses is the inductively-coupled plasma-atomic emission spectroscopic technique. Unfortunately, even the excellent powers of detection achieved by this technique are occasionally inadequate if the effluents are analyzed directly. Stray and scattered light effects arising from changing concentrations or certain elements, such as Ca or Mg, in the geothermal effluents may arise to subtle background interference effects. The latter may give rise to significant errors, especially when quantitative determinations are made near detection limit concentrations.

Two related studies are supported under this project. One is focused on the development of innovative methods for preseparating the ultratrace metals from geothermal effluents. New chelating resins with macroreticular oganic matrices are now being developed for this purpose. The other project is focused on identifying the origin of the stray and scattered light effects and on devising means of reducing their magnitude to negligible or correctible proportions.

A new chelating resin has been synthesized which contains a propylenediaminetetraacetic acid (PDTA) functional group attached to a macroreticular DVB resin via a carboxylic acid ester linkage. The new resin has two major advantages over the Chelex 100 chelating resin that has been used to concentrate trace metal ions from saline waters: (1) The PDTA functional group complexes metal ions more strongly than the iminodiacetic acid group (IDA) on Chelex 100, (2) The kinetics of the new resin for complexing metal ions are more favorable. Recovery of 16 trace metal ions added to saline water in 0.5 ppm concentration each showed excellent recovery at pH 6. Quantitative recovery of most of the metal ions was obtained anywhere within a range of pH 3 to 8.

Aluminium (III) and manganese (II) were tested as carriers for isolation of trace metal ions from sea water because they have fewer atomic spectral lines than iron (III). However, iron proved to be a more efficient carrier than the others.

Stray and scattered light levels in commercial spectrometers have been reduced to detection limit levels or less for most elements through the use of state-of-the art gratings (especially holographically deposited gratings) and by the elimination of as many scattering or reflecting surfaces inside the spectrometer as possible. Empirical correction factors based on the concentration of the element (concomitant) that causes the stray light have been successful over a limited concentration range. It has been shown that narrow bandpass interference filters reduce the far scatter stray light arising from Ca concentrations as high as 2000 ppm down to negligible proportions. These filters reduce the Mg far scatter stray light as well, but not as much as predicted by the percent transmission of the filter.

The nature of the background shift caused by Mg is now under study.

Our key to the solution of the matrix-related background changes is first, the elimination of as much of the problem as possible (e.g. the reductions in stray light already accomplished) and second, the development of methods capable of either compensating for any remaining matrix related background shifts, or measuring the shifts directly by simultaneous multichannel techniques now under study by an ERDA supported project. No insurmountable problems are foreseen in developing viable approaches based on the most effective ways of eliminating or correcting these subtle background effects.

DEVELOPMENT AND EVALUATION OF IMPROVED RADIOLOGICAL ASSESSMENT CAPABILITIES

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INTRODUCTION

Assessments of the radiological impact of a nuclear power plant are conducted before and during plant construction to conform with requirements related to granting a construction permit and an operating license. Similar assessments are conducted during plant operation to conform with requirements related to preparing reports on operation and environmental monitoring. Empirical data and analytical models are used for these assessments.

Mathematical models, in the form of computer programs with theoretical or empirical data, are used to predict the radiological impact of releases from a nuclear power plant. The models contain many variables, each of which has a range of uncertainty associated with it. Generally, conservative values are used for these variables unless the use of more realistic values can be justified. The magnitude of the impact predicted by these models can influence the cost of constructing and operating a nuclear power plant. Revision of the models is critically needed to permit production of more accurate, realistic assessments of the impact of the facility and to facilitate the economic development of nuclear power.

To assess the impact of an operating plant accurately, appropriate personnel must combine data regarding plant releases with data from environmental surveys. All such data should be obtained from effective radiological surveillance programs at the specific power facility. Data concerning the release of effluents and the environment must be accurate and reliable to assess properly the environmental impact of a specific facility. Refinement and testing of the analytical models for calculating potential movement of radionuclides from a plant to its environs and the associated impacts of that movement depend on the comparability of in-plant and environmental data. Likewise, the assessment of regional and national effects of nuclear power production depends on the comparability of empirical data generated throughout the nuclear power industry.

A primary objective of this project is to provide guideline information to the nuclear power industry for developing an optimum radiological monitoring program. Our studies have been divided into three major subareas: (1) development of a model intraorganization program of quality assurance for radiological surveillance that will include all TVA environmental and nuclear plant laboratories; (2) improvement of radiological monitoring techniques with emphasis on gamma spectroscopy methodologies, which are among the most frequently employed analytical tools; and (3) evaluation of existing environmental radiological surveillance programs. The end product will be a surveillance program capable of meeting required analytical sensitivities and providing adequate information for assessment in a cost-effective manner.

This project is further designed to evaluate and refine the models used to predict the radiological impact of atmospheric releases from nuclear power plants. Gamma-radiation exposure rates measured at various locations in the vicinity of an operating plant are compared with values predicted by the models. Direct radiation from radioactive materials confined within the plant will contribute to the exposure rates measured at some locations; therefore, models for assessing exposure to direct radiation also will be evaluated and refined.

TECHNICAL DISCUSSION

Quality Control

A quality assurance program is being developed to (1) help demonstrate the accuracy and reliability of output empirical data and (2) serve as a model for the nuclear industry. The Radioanalytical Laboratory at Muscle Shoals, the Browns Ferry Nuclear Plant (BFNP) laboratory, and the Sequoyah Nuclear Plant (SNP) laboratory are participating in this program. We anticipate participation from all future nuclear plant and environmental laboratories developed within TVA.

The Analytical Quality Control Program will provide each participant with (1) information on quality control, (2) a single source of calibrated radioactive materials and custom calibration standards, (3) an analytical cross-check program, and (4) assistance in developing new capabilities. A part of the quality control work has been to write a Handbook for Analytical Quality Control in Radioanalytical Laboratories for TVA laboratories. The Environmental Protection Agency (EPA) has suggested that project staff modify and expand the manual so that a larger audience can adapt the information to its particular needs. The manual will be prepared for publication during this fiscal year. The manual provides guidelines for established laboratories and for new laboratories with little or no radiological experience. Adherence to the guidelines should enable new laboratories to meet the requirements of the new regulations for drinking water proposed by EPA.

The quality control laboratory is stocking and supplying calibrated radioactive material and providing custom calibration standards to all participating laboratories. Custom sources prepared from multinuclide radioactive solutions calibrated by the National Bureau of Standards are prepared for the environmental laboratory at Muscle Shoals and the BFNP laboratory. These standards are used to calibrate germanium detector systems at both laboratories. Cross-check standards for tritium in water, multinuclide gamma sources in water, and strontium in wastewater are being prepared.

Seminars on liquid scintillation counting have been presented by project staff at each participating laboratory. Similar seminars may be presented to new laboratories as they are staffed. As another part of the quality control program, we helped the Radioanalytical Laboratory at Muscle Shoals to assemble and calibrate a new beta-gamma coincidence system for iodine determination in milk and a radon counting system for environmental samples.

Gamma Spectroscopy

Certain widely used analytical methods are being investigated. Gamma spectroscopy is a powerful technique for identifying and quantifying radionuclides. Cost per analysis is quite low because costly chemical separations are not required. The proper application of thallium-activated sodium-iodide [NaI(Tℓ)] detectors and germanium detectors to gamma spectroscopy is the subject of controversy since each detector has its own particular merits and drawbacks. The advantages of the NaI(Tℓ) detector systems are high efficiency and low capital cost, whereas the advantages of the germanium detector systems are high resolution and ease of calibration. Thus, a radiological program may use either detector, or use each in the task for which it is best suited. The detailed comparison of the two types of detector systems that is planned for this project will assist in the selection of the best detector for a particular application.

The most effective method for extracting quantitative data from NaI(Tℓ) spectra is a least-squares analysis program. Several least-squares programs exist, but none have been tested at environmental levels of activity. The report "Least-Squares Resolution of Gamma-Ray Spectra in Environmental Monitoring," prepared by project staff, evaluates the program ALPHA-M for environmental monitoring. The report provides documentation for the program and gives specific descriptions of (1) the best processing options, (2) the lower levels of detection obtainable, (3) experiments to verify the lower levels of detection, (4) guidelines for establishing the program performance from the standards library selected, (5) methods for predicting the performance of a given library, and (6) methods for performing some simple statistical tests to evaluate the routine data produced by ALPHA-M.

A study of the applicability of germanium detectors to environmental monitoring will be completed soon. This study focuses on (1) providing a set of tested quality control procedures for germanium detector systems; (2) investigating practical optimum counting geometries; (3) determining the practical lower limits of detection for certain nuclides using these optimum geometries; and (4) preparing a comparison of NaI(Tℓ) crystals and germanium detectors that considers sensitivity, system cost, calibration requirements, and maintenance.

Optimum counting geometries have been determined for gamma spectroscopy systems using certain practical considerations as selection criteria--for example, the difficulty of collecting and transporting large volumes or masses of potentially perishable samples. This problem and others of a pragmatic nature were considered when the counting geometries were determined. In the design of optimum monitoring programs, these data can supply the scientist with a reliable measure of the detection capability of certain gamma spectroscopy systems.

Environmental Monitoring

The third objective in optimizing programs for environmental radiological surveillance for nuclear power plants has two parts: (1) to critically evaluate existing environmental radiological surveillance programs and (2) to design an optimized, cost-effective program for environmental radiological surveillance. This objective is being addressed by research and base program personnel within TVA. A historical data base is being developed to include data from all facilities in operation or under construction as part of TVA's nuclear activities. The data base is being set up on the IBM system, using COBOL as the basic programming language and FORTRAN IV as the accessory language for data analyses. Other utilities, agencies, or institutions should be able to develop similar data base systems with only minor programming modifications.

An extensive statistical analysis of the available data has been initiated (some simple analyses have been performed on the limited data now in the base). Because better information regarding analytical sensitivities is available as a result of the study of ALPHA-M performed in this research project and because data now being added to the base include estimates of uncertainties, a better data set than others have had is available. Consequently, the worth of present monitoring programs similar to TVA's program can be evaluated.

The actual optimization phase of the study is in its infancy. Information provided by the environmental surveillance review committee of the Radiological Hygiene Branch, established to ensure that TVA's radiological surveillance program meets applicable regulatory requirements at minimum cost, will be used. Data on monitoring systems used by other utilities, agencies, and institutions will also be gathered. Consideration will be given to vectors or exposure pathways to be monitored, monitoring site selection, sampling methodologies, and sampling frequencies.

We anticipate the development of alternative designs for radiological surveillance programs. Using statistical and cost-effectiveness analyses, we will gather data for refining the various alternatives. After these alternative designs are evaluated, a specific surveillance program will be recommended. To the extent possible, we will colect field data to evaluate the worth of the recommended program.

Analytical Model Refinement

The refinement and evaluation of analytical models involve (1) collection of empirical data with which to test the currently available models and (2) studies to test the sensitivity of the models. Pressurized ionization chamber (PIC) systems are being used to measure rates of exposure to gamma radiation in the vicinity of BFNP. During the period that the plant was shut down for repairs, distributions of background or nonoperational exposure rates were characterized at about 83 locations on or near the plant site.

Data collected since BFNP resumed power production in September 1976 have not been fully evaluated. A cursory examination of the data indicates that (1) increases in exposure rate caused by radioactive materials confined within the plant are easily identifiable at several locations close to the plant and (2) increases in exposure rate caused by radioactivity in gaseous effluents may be difficult to identify or quantify.

Increases in the measured exposure rates caused by gaseous effluents from BFNP are expected to be small in comparison with background and may not be readily distinguished from fluctuations in the background exposure rates. Therefore, methods of identifying a contribution from a plume were investigated. One method is based on the observation that the presence of a plume causes the exposure rate to fluctuate more rapidly than is observed when background alone is measured. This fluctuation causes (1) an increase in the standard deviation associated with the mean of the set of measurements and (2) a change in a log-normal plot of the measurements from a similar plot of measurements of background alone. Preliminary investigations of this method using data collected since operations resumed at BFNP indicate that the effects of the gaseous effluent plume on the exposure rate can be observed, but that quantification of the effects may not be possible in all cases. Another method of detecting and quantifying the effect of a plume is based on a Latin-square experimental design. These and other methods are being or will be applied to data collected during plant operation. Further development of methods for detecting and quantifying the effect of the gaseous effluent may be necessary to complete the comparison of the observed increases in exposure rate with the values calculated for exposure rate caused by the gaseous effluent.

A study of the assessment models will be performed to determine ranges or combinations of values for variables to which the models are particularly sensitive. This information will be helpful in determining the areas in which the most benefit will be derived from refinement of the models and values assigned to the variables within the models.

In addition to characterizing the levels of background radiation in the vicinity of BFNP, the data collected to date have provided information regarding the performance of PIC systems used in this study. The data showed that, although the instruments were in close agreement with one another, small, but statistically significant, differences were observed. Similarly, small discrepancies between the two modes of instrument operation, the integral mode and the rate mode, were observed in some instruments. The discrepancies are believed to be caused by small errors in the calibration of the PIC systems. Experiments are being planned to quantify these discrepancies accurately. Persons using PIC systems for studies requiring accuracy and precision should consider rigorous calibration of all instruments.

CONCLUSIONS

Results of this study are being used and are expected to be used in the near future by Federal, state, local, and private agencies and organizations. The quality assurance handbook prepared in this study will be the first comprehensive, widely distributed document to discuss quality control in radioanalytical laboratories. With the promulgation of regulations on drinking water and the consequent increase in the number of laboratories performing radiological analyses, distribution of the document may provide the means to assure data comparability among all environmental laboratories, established or new.

The multiple-laboratory, intraorganization program for quality control is providing and will provide valuable information regarding (1) maintenance of such a program and (2) assurance of comparability of data between environmental and nuclear power plant laboratories. The study will also provide information for use by organizations such as EPA that are responsible for interorganization programs for quality control.

As a result of the methodologies for gamma spectroscopy, interested organizations have and will have documented information regarding the resolution of complex gamma spectra and the assignment of lower levels of detection. Information suitable for comparing NaI(Tl) and germanium detector systems is also being provided.

The study of environmental radiological surveillance programs is expected to provide essential information for establishing cost-effective surveillance programs of high worth. This part of the program will be emphasized in the upcoming years of the project.

In evaluating the analytical models used for impact assessment, project staff are (1) developing methodologies for effluent plume detection and quantification and (2) obtaining information regarding the use of PIC systems in studies requiring accuracy and precision. Results of the study are expected to include (1) development of refined analytical models capable of providing realistic assessments of radiological impact and (2) guidelines for establishment of environmental surveillance programs.

To supplement the ongoing work, additional studies should be performed in two areas:

1. Environmental radiological surveillance programs. Field testing of surveillance programs proposed in the ongoing study and evaluation of exposure pathways not considered in detail in the present study should be conducted to assure proper measurement of environmental impact.

2. Analytical model refinement. Additional work is necessary regarding the collection of radionuclide-specific data around large nuclear facilities. Availability of these data may be necessary to formulate a defensible series of models for assessing radiological impact.

The combination of the ongoing work and the proposed work will provide the means for realistically assessing the predicted and actual impact of electrical generation by nuclear power plants.

CHEMICAL CONSTITUENTS FOUND IN WASTES FROM COAL CONVERSION AND OIL SHALE PROCESSING

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INTRODUCTION

Experience has taught us that a thorough knowledge of the chemical constituents in waste effluents from industrial plants is invaluable in determining whether a chemical monitoring method is needed for the discharge. The first step, therefore, in developing methods for monitoring wastes from energy-related industries should be a comprehensive chemical analysis of the effluents of concern. In addition, the developed information should be valuable in devising pollution control strategies and in planning studies to determine the environmental impact of these energy-related industries.

In November 1975, the Environmental Protection Agency awarded a 1-year contract (contract no. 68-03-2368) to the Research Triangle Institute (RTI), Research Triangle Park, NC, to identify and measure chemical constituents in liquid and solid wastes from several energy-related industries, with coal conversion and oil shale processes the first to be studied. At the same time this project began, a considerable number of projects to assess human health effects of pollutants and to develop control technology for energy related activities were beginning or in progress. To minimize unnecessary duplication of effort, RTI was required to first review pertinent scientific and governmental literature to take advantage of all acceptable information that had already been or would likely be developed by other projects.

After this review was completed, RTI investigators identified information gaps, sampled appropriate energy projects presently in operation, and performed chemical analyses of effluent for chemical elements and volatile organic compounds (those that will pass through a gas chromatograph without decomposing). This paper describes the information that will be provided in greater detail in the final project report, which is in preparation.

REVIEW OF TECHNICAL REPORTS AND CURRENT PROJECTS

As expected, collection of information on completed or ongoing projects was difficult because very little of the chemical characterization had been completed and because most of the completed work was not reported in the open literature. These factors indicated the need for the review to be updated continually throughout the project. Examples of the information for technical reports and current projects that will be presented in RTI's final report are given in Figures 1 and 2. To date, the review lists 6 technical reports and 3 current projects that concerned environmental effects of oil shale processing along with 51 technical reports and 5 current projects involving coal conversion. In general, elemental analysis was more comprehensive than analysis for organic compounds. In fact, most analyses of materials for organic components reported in the literature were limited to one or two classes of compounds and usually were performed without the benefit of a mass spectrometer or other highly specific detector. Two notable exceptions were reports by the Bureau of Mines on the Synthane process for coal gasification (1, 2). Even in these reports, however, the authors indicated a need for further characterization.

Title: Comparison of Pitch Resins from Different Sources by Combined Pyrolysis and Gas-Liquid Chromatography

Authors: C. Karr, Jr., J. R. Comberiati and W. C. Warner

Performing Organization: Morgantown Coal Research Center, Morgantown, WV

Sponsoring Agency: Bureau of Mines, U.S. Dept. Interior, Morgantown, WV

Report No./Journal: Anal. Chem., 35, 441 (1963)

NTIS/GPO No.: NA   Type of Report: Publication

Figure 1. Example of Technical Reports.

Title of Project: Slagging Fixed Bed Coal Gasification

Principal Investigator: R. C. Ellman

Performing Agency: U.S. ERDA, Grand Forks Energy Research Center, Grand Forks, ND 58202

Supporting Agency: U.S. ERDA

Agency's Number(s): Unknown

Project Period: 7/1/74 - 6/30/80

Funds: FY75 - $180,000

FY76 - $600,000

Figure 2. Example of Current Project Reports.

For six types of energy activities, RTI tabulated all elements and all organic compounds identified in the reports reviewed: 41 chemical elements and 61 organic compounds were found in effluents from coal conversion or oil shale processing.

CHEMICAL ANALYSIS

Methods for Elemental Analysis

Elemental analysis was performed by spark source mass spectrometry under a sub-contract to Commercial Testing and Engineering Company, Golden, CO. Spark source mass spectrometry can identify and measure all of the chemical elements except the ten that occur naturally as gases and may be lost during sample preparation. Sensitivity is approximately the same for all elements, 1 mg/kg for solids and 10 μ/l for liquids. Because of its volatility, mercury was determined by the cold-vapor atomic absorption technique.

Methods for Organic Analysis

Purgeable compounds were separated by purging an aliquot of the sample with helium and collecting the compounds on Tenax resin. The trapped compounds were recovered by thermal desorption and analyzed by glass capillary gas chromatography-mass spectrometry.

Non-purgeable volatile compounds were extracted at three different pH levels with freon. The extracts were concentrated in a Kuderna-Danish apparatus, and the concentrates were analyzed by gas chromatography with flame ionization and mass spectrometric detectors. Identification of resolved components was achieved by comparing the mass fragmentation patterns of the unknown with mass spectra of known compounds. Quantitation was performed by relating the mass spectrometer ion current monitor response for identified compounds to the response for internal reference compounds whose relative responses had previously been related to the sample compound (either specifically or by class). The extraction, concentration, and analytical procedures used were designed to permit identification and quantitation of organic compounds present in the samples at concentrations of 1 μg/l or greater.

Samples

Forty-five samples have been analyzed from *in situ* coal gasification plants at Hanna and Gillette, WY; from a low-BTU coal gasification pilot plant at Morgantown, WV; and from *in situ* oil shale gasification projects at DeBeque, CO, and Laramie, WY. Analyzed samples included coal seam water, product water, product tar, ground water and liquid condensate from coal gasification, oil shale formation water, discarded cavern oil shale, and boiler blow-down water from oil shale operations.

Reported Data

Two examples of reported data will illustrate the complexity of some of the analyzed samples. In some samples, more than 200 organic compounds were reported. Although specific isomers of some components were not distinguishable (such as C_4-alkyl benzenes, TABLE 1), these analyses provide specific information that was previously unavailable for these particular energy processes.

TABLE 1. VOLATILE ORGANICS IN PRODUCT WATER SAMPLE #1 DURING WELL 5-6 *IN SITU* COAL GASIFICATION

Chromatographic Peak No.	Elution Temp. (°C)	Compound	ppb
3	59-61	acetaldehyde	34±5
4	62-6	acetone	9330±100
5	66	methyl cyanide	17.0±15
8	72	CS_2	NQ
9	75	*n*-propylamine (tent.)	17.0±2
10	77	$_6H_{10}$ isomer	NQ
11	79	propane nitrile	2000±55
13	83-5	methyl ethyl ketone	5000±0
16	90	2-methylpropane nitrile + unknown	100±2
17	92	perfluorotoluene (e[illegible])	-
18A	99	methyl isopropyl ketone	trace
19	99-100	benzene	6670±70
20	101	thiophene	67±18
21	104	*n*-butyronitrile	117±0
22	105	2-pentanone	4700±800
23	107	3-pentanone	2330±500
25	112	α-methylbutyronitrile	17±8
27	115	sulfur compound (?)	NQ
28	116	N-methylpyrrole	33±16
30	118	4-methyl-2-pentanone	67±7
31	120	2-methyl-3-pentanone	83±21
32	122	pyrrole	5000±500
33	123	*n*-pentane nitrile	133±33
34	124	toluene	5000±100
34A	124-132	pyridine	trace
34B	124	2-methylthiophene	trace
35	126	3-methylthiophene + 3-hexanone	330±28
36	127	2-hexanone	670±55
37	129	cyclopentanone	167±35
38	133	C_8H_{18} isomer	33±21
41	140	3-methylpyrrole	1667±170
42	141	2-methylcyclopentanone + 3-methylpyridine	670±225
43	142	2-methylpyrrole	1660±1100
44	144	4-methylpyridine	33±17
45	147	ethylbenzene	1660±10
45A	148	C_8H_{16} isomer	trace
46	149	*p*-xylene	2670±25

(continued)

TABLE 1 (continued)

Chromatographic Peak No.	Elution Temp. (°C)	Compound	ppb
47	151	2,5-dimethylthiophene + aniline	67±15 17±8
48	152	2-heptanone	100±50
49	154	styrene	1300±210
49A	154	C_8H_{16} isomer	trace
50	155	*o*-xylene	1300±333
51	157	dimethylpyridine isomer	1670±945
51A	158	C_9H_{20} isomer	trace
52	159	dimethylpyrrole isomer	1000±250
52A	160	dimethylpyridine isomer	trace
52B	161	dimethylpyrrole isomer	trace
53	162	isopropylbenzene + dimethylmethylpyridine isomer	33±17
54	164	ethyl pyrrole (tent.)	NQ
55	167	methylpyridine isomer	NQ
56	169	*n*-propylbenzene	167±25
57	170	*m*-ethyltoluene	3300±334
58	171	*p*-ethyltoluene	2.67±1
59	173	2-isopropylthiophene (tent.)	16.7±5
60	174	cyanobenzene	2670±352
60A	174	trimethylpyridine (tent.)	trace
61	175	*o*-ethyltoluene	2000±299
62	176	$C_{10}H_{20}$ isomer + methylethylpyridine isomer	300±206
63	176	α-methylstyrene	2500±271
63A	177	1,2,4-trimethylbenzene	6670±491
63B	178	benzofuran + *n*-decane	1330±826
63C	179	ethyl pyrazine (tent.)	NQ
64	180	trimethyl thiophene isomer	1330±279
65	182	C_4-alkyl benzene isomer	167±38
66	183	1,2,3-trimethylbenzene	2670±811
67	186	dimethylaniline isomer	58±40
67A	187	trimethylpyridine isomer	trace
68	188	indane	1000±210
68A	188-195	phenol	6700±3990
69	190	indene	1000±675
70	191	C_4-alkyl benzene isomer	340±45
71	192	methylcyanobenzene isomer	830±800

TABLE 1 (continued)

Chromatographic Peak No.	Elution Temp. (°C)	Compound	ppb
72	193	$C_{10}H_{20}$ + C_4-alkyl benzene isomers	23±4
73	195	C_4-alkyl benzene isomer	500±25
74	196	$C_{10}H_{12}$ isomer	840±98
75	197	*o*-cresol	1730±1110
76	198	methylindane isomer	trace
77	199	*n*-undecane	187±91
78	201	methylbenzofuran isomer	3000±117
79	202	2-ethylphenol	1000±177
80	204	C_4-alkyl benzene isomer	670±392
81	205	methyl indane isomer + C_5-alkyl benzene isomer	trace trace
81A	206	dimethylindane isomer	trace
82	207	*p*-cresol	1660±778
83	208	C_5-alkyl benzene isomer	0.06±0
84	209	methylindane isomer	00.3±0
84A	210	methylindene isomer	trace
84B	210	$C_{10}H_{12}$ isomer	1.0±1
85	211	C_4-alkyl benzene isomer	1.5±1.5
86	212	*m*-cresol + C_5-alkyl benzene isomer	2000±670
87	214	3-ethylphenol	5000±1200
	215	$C_{12}H_{24}$ isomer	NQ
88	216	2,4-dimethylphenol	5330±1555
89	218	*n*-dodecane	4000±100
90	219	naphthalene	13340±134
91	220	dimethylindane isomer + benzothiophene	1340±888
91A	221	C_6-alkyl benzene isomer	trace
92	222	4,7-dimethylbenzofuran	1000±700
93	223	dimethylphenol isomer	trace
94	224	5,6-dimethylbenzofuran	trace
95	225	C_6-alkyl benzene isomer	trace
96	226	C_5-alkyl benzene isomer	trace
97	227	C_6-alkyl benzene + C_3-alkyl phenol isomer	1000±970
98	228	dimethylindene isomer	1660±170
99	229	dimethylindane isomer	1000±170

(continued)

Table 1 (continued)

Chromatographic Peak No.	Elution Temp. (°C)	Compound	ppb
100	229	1-phenyl hexane	67±15
101	230	methyl dihydronaphthalene isomer	670±76
102	232	methyl dihydronapthalene isomer + C_3-alkyl indane isomer	800±136
103	233	1-tridecene	900±376
104	235	n-tridecane	5000±500
	236	trimethylindane isomer	NQ
106	237	C_3-alkyl phenol isomer	800±475
107	239	α-methylnapthalene	2830±284
107A	240	2-isopropylbenzimidazole isomer	trace
108	isothermal	β-methylnapthalene	2000±100
109		$C_{12}H_{16}$ isomer (tent.)	68±34
110		$C_{13}H_{18}$ isomer	100±52
111		$C_{14}H_{30}$ isomer	117±27
112		C_7-alkyl benzene isomer	150±75
113		$C_{15}H_{32}$ isomer	670±300
114		1-tetradecene	1000±277
		biphenyl	5330±534
115		n-tetradecane	2330±460
116		$C_{13}H_{18}$ isomer	trace
117		$C_{13}H_{18}$ isomer	trace
118		ethylnaphthalene isomer	1670±710
118A	240	$C_{12}H_{14}$ isomer	trace
119		dimethylnaphthalene isomer	2000±1120
120		dimethylnaphthalene isomer	670±300
121		dimethylnaphthalene isomer	1330±710
122	isothermal	$C_{16}H_{34}$ isomer	167±49
123		dimethylnaphthalene isomer	160±130
124		biphenylene + ethylnaphthalene isomer	1700±491
		$C_{15}H_{30}$ isomer	trace
125		n-pentadecane	trace
128		acenaphthalene	1690±170
129		isopropyl naphthalene isomer	NQ
130		C_3-alkyl naphthalene isomer	trace
131		tetramethyl indane (tent.)	trace
135		trimethylnaphthalene isomer	NQ
137		$C_{16}H_{32}$ isomer	1700±170
138		n-hexadecane	2660±271

The chemical elements present were reported in alphabetical lists of detected elements accompanied by concentration data (TABLE 2). Seventy-four elements were considered routinely.

Table 2. ELEMENTAL CONCENTRATIONS IN LIQUID CONDENSATE #5 FROM ROSEBUD COAL DURING LOW BTU COAL GASIFICATION

Element	ppm[a]
Aluminum	0.5 ± .45
Antimony	0.06 ± .02
Arsenic	1 ± 0
Barium	0.025 ± .005
Beryllium	<0.02
Bismuth	<0.02
Boron	0.4 ± .2
Bromine	0.02 ± 0
Cadmium	<0.02
Calcium	2.4 ± 1.7
Cerium	<0.02
Cesium	0.01 ± 0
Chlorine	0.23 ± .17
Chromium	0.06 ± .01
Cobalt	0.008 ± .002
Copper	0.2 ± .1
Dysprosium	<0.02
Erbium	<0.02
Europium	<0.02
Fluorine	0.6 ± .4
Gadolinium	<0.02
Gallium	<0.02
Germanium	<0.02
Gold	<0.02
Hafnium	<0.02
Holmium	<0.02
Indium	[illegible]
Iodine	<0.02
Iridium	<0.02
Iron	2.5 ± 1.5
Lanthanum	<0.02
Lead	0.1 ± 0
Lithium	0.020 ± .015
Lutetium	<0.02
Magnesium	0.7 ± .4
Manganese	0.04 ± .02
Mercury[b]	<0.001
Molybdenum	<0.02
Neodymium	<0.02
Nickel	0.85 ± .05
Niobium	<0.02
Osmium	<0.02
Palladium	<0.02
Phosphorus	0.07 ± .02
Platinum	<0.02
Potassium	0.23 ± .17
Praseodymium	<0.02
Rhenium	<0.02
Rhodium	<0.02
Rubidium	0.05 ± .04
Ruthenium	<0.02
Samarium	<0.02
Scandium	0.02 ± .015

(continued)

TABLE 2 (continued)

Element	ppm
Selenium	0.04 ± 0
Silicon	2.0 ± 1.1
Silver	<0.02
Sodium	1.0 ± .9
Strontium	0.015 ± .005
Sulfur	MC
Tantalum	0.3 ± .3
Tellurium	<0.02
Terbium	<0.02
Thallium	<0.02
Thorium	<0.02
Thulium	<0.02
Tin	<0.02
Titanium	0.1 ± 0
Tungsten	0.07 ± .07
Uranium	<0.02
Vanadium	0.033 ± .027
Ytterbium	<0.02
Yttrium	<0.02
Zinc	0.25 ± .2
Zirconium	0.02 ± .02

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[a] Detection limit was <0.02

[b] Determined by flameless AA.

SIGNIFICANCE

Any discussion of the environmental significance of the results reported in this project is beyond the scope of this paper; however, because of the importance assigned recently to the consent decree priority pollutants, it is of interest that 7 of the 13 consent decree elements were reported at concentrations ranging from 0.04 to 1.0 ppm (Table 2) and that 6 of the 108 consent decree organic compounds are reported at concentrations ranging from 1,660 to 13,340 ppb (Table 1).

FUTURE PLANS

Another EPA contract, which was recently awarded to Gulf South Research Institute, will provide analogous information about effluents from several energy activities, including coal gasification and liquefaction, oil shale processing, coal mining, and coal-fired power plant operations. Sampling will continue at some sites mentioned in this paper, and the review of related projects will continue to be updated periodically.

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MEASUREMENT STANDARDS FOR WATER MONITORING ASSOCIATED WITH ENERGY PRODUCTION AND USE

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This paper presents a summary of work being performed by the National Bureau of Standards on the development of measurement methods and standards for water monitoring associated with energy production and use. In a separate paper presented at this symposium, the corresponding air pollution measurement standards work of NBS is described.

The first area of work to be described is the development of Standard Reference Materials for the analysis of energy related water pollutants. Standard Reference Materials (SRM's) are materials with accurately characterized properties and are designed to test the accuracy and reliability of measurement methods. SRM's can also serve as a point of comparison for measurements made at different times on different locations by different analysts. Comparability is achieved through a carefully documented series of comparisons of SRM's with quality control samples, working standards and calibration standards. SRM's are sold by NBS at a cost sufficient to recover production expenses and are accompanied by a certificate which not only gives the certified values for the properties of interest but also contains the name of the scientist who had responsibility for the certification and additional information on the preparation and use of the SRM. The SRM program at NBS has been reviewed recently by Cali [1].

The SRM development activities are coordinated with the Environmental Monitoring and Support Laboratory of EPA in Cincinnati except for radioactivity standards which are coordinated with the Environmental Monitoring and Support Laboratory of EPA in Las Vegas.

During the first year of this program, workshops were held to determine the SRM needs for the analysis of effluents associated with various industrial operations. These included: Off-Shore Petroleum Production, Oil-Shale Processing, Coal Gasification and Liquefaction, Coal Desulfurization, Power Plant Operation, Mine Drainage, Uranium Mining and Geothermal Energy Production. The Proceedings of these workshops are in preparation but the SRM needs in priority order are available and are presented in Table 1.

TABLE 1. STANDARD REFERENCE MATERIALS NEEDED FOR ENVIRONMENTAL MONITORING ASSOCIATED WITH ENERGY PRODUCTION AND USE

Technology Area	Material[a]	Certified Properties
Off-Shore Petroleum Production	1. Sediment	Trace Elements and Hydrocarbons
	2. Biological Tissue	" " "
	3. Synthetic Mixture of Pure Organic Compounds	Concentrations of Individual Compounds
	4. Reference Crude Oil	Homogeneity
	5. Sea Water	Trace Elements and Hydrocarbons
Oil Shale Production	1. Raw Oil Shale Containing Approximately 100 Liters/Metric Ton, ≤ 200 mesh	Homogeneity
	2. Spent Shale	"
	3. Shale Oil	"
	4. Process Water	Trace Elements and Hydrocarbons
Coal Gasification and Liquefaction	1. Western Sub-bituminous Coal	Trace Elements
	2. Product Oil	Homogeneity
	3. Bottom Ash[b]	Trace Elements
	4. Aqueous Effluent Containing Organic Fraction	Homogeneity
	5. Gas Blends of H_2S, COS, Thiophenes and Mercaptans in Methane and Carbon Dioxide	Concentration
	6. Char (from Lurgi Process)	Homogeneity
	7. Eastern Coal[c]	Trace Elements
	8. Fly Ash[c]	"

(continued)

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TABLE 1 (continued)

Technology Area	Material[a]	Certified Properties
Coal Desulfurization	1. Eastern Coal and Fly Ash	Inorganic and Organic Sulfur, Additional Trace Elements
	2. Fly Ash	Polynuclear Aromatic Hydrocarbons
	3. Bottom Ash	Sulfur and Trace Elements
	4. H-Coal Product	" "
	5. Western Coal and Coal Fly Ash[d]	Trace Elements
	6. Gas Blend of H_2S in Nitrogen	Concentration
	7. H_2S Permeation Tube	Permeation Rate
	8. Scrubber Sludge	Trace Elements
	9. Fly Ash Pond Effluent	Trace Elements
Power Plant Operation	1. Particle Standard	Size Distribution in .01 to 100 µm range
	2. Surface Thickness Standard	Pb on 50 µm Particles
	3. Vinyl Chloride in Air	Concentration
	4. Water	Oil and Grease, 10 to 50 mg/Liter
	5. Air Particulates on Filters (Fly Ash and Ambient)	Trace Elements
	6. Coal and Fly Ash	Additional Trace Elements
	7. Fly Ash Leachate	Trace Elements
	8. Air Particulates	Polynuclear Aromatic Hydrocarbons
	9. Water	As^{+3}, As^{+5}, CH_3As, Sb^{+3}, Sb^{+5}, CH_3Sb, Hg^{+2}, CH_3Hg, Cr^{+3}, Cr^{+6}, Organic Cr
Mine Drainage	1. Unpolluted, Fresh Water Sediment	Trace Elements
	2. Effluent Water	Elements
	3. Polluted Water	Trace Elements
	4. Unpolluted Marine Sediment	Trace Elements
	5. Powdered Spoil Material	Homogeneity
Uranium Mining	1. Uranium Ore, 21% High Barium Content, Secular Equilibrium For Nuclides	Pb-210, Th-230, Ra-226, U, Pa-231, Po-210
	2. Uranium Ore Raffinate	Radionuclides
	3. Uranium Ore	Trace Elements
	4. "Blank" Soil (Dunnite)	Trace Elements and Radionuclides
	5. Thorium Ore	Thorium and Ra-228
	6. Water	Pb-210.
	7. Soil	U, Th-230, Ra-226, Po-210, Pb-210
Geothermal Energy Production	1. H_2S in Blend of 50% CO_2 and 50% Air	Concentration
	2. Geothermal Water	Trace Elements
	3. Cooling Tower Sludge	Trace Elements

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[a] Listed in order of decreasing priority.

[b] If substantially different in composition from fly ash.

[c] Reissuance of NBS SRM's

[d] If substantially different in composition from Eastern coal and fly ash.

Support under this program has been used to accelerate the development of a trace element in water SRM, issuance of which is expected in August 1977. The SRM will consists of 16 certified trace elements in concentrations ranging from 2 ppb to 100 ppb and four "matrix elements" (Na, K, Ca, and Mg) in the low ppm range.

A method has been developed which may be used to generate known concentrations of organic compounds in water. The compound of interest is coated on glass beads packed in a column. When water is flowed through the column, the effluent contains a saturated solution of the compounds. Experiments to date have demonstrated that the concentration is a reproducible function of temperature and, following a conditioning period, independent of flow rate. Future efforts will determine the suitability of this device as a standard reference material.

The development of radioactivity standards is mostly directed at the measurement of alpha particle emitting radionuclides. To date a ^{210}Po standard, a mixed gamma ray solution standard and a mancos shale standard certified for ^{226}Ra and ^{228}Ra have been completed.

The second area of work is the development of energy related water pollution analysis instrumentation and is coordinated with the EPA Environmental Research Laboratory in Athens, Georgia. This effort is directed toward the determination of organic and organo-metallic compounds likely to result from coal gasification and liquefaction plants, from coal fired power plants and from oil shale production.

In order to develop a method to determine the concentration and identification of chemical forms of particular elements three projects have been initiated. In the first, a combination of liquid chromatography with electrochemical detection is being studied for the determination of organic complexes of cadmium, lead, copper and mercury. A second method, selective dissolution for the separate determination of As-III and As-V, proved to be unreliable, but did lead to an improved method for total arsenic. The third method, dual plasma spectrometry, is based on heating an environmental sample and examining the vapor above the sample as a function of temperature. The vapor is directed into a plasma flame and the element of interest is determined by atomic emission spectroscopy. Distinct species of mercury in water, sea water and orchard leaves, chromium in yeast and lead in air, orchard leaves and steel have been detected though not identified.

Work is now beginning on method development for the measurement of trace organic compounds in water. Marker compounds will be selected and incorporated into analytical procedures in order to quantify organic compounds detected using gas chromatographic methods. A marker compound is an internal standard added as a spike when a water sample is collected and which behaves in a similar way the compounds to be determined. Work is also in progress on the development of liquid chromatographic separation methods for polar organic compounds. In order to assess the method, specific hydroxylated polynuclear aromatic hydrocarbons are being prepared. Two detection methods, cerium oxidation and electrochemical, will be evaluated for use in the determination of hydroxylated polynuclear aromatic compounds. Finally, instrumentation is being assembled to allow coupling of mass spectroscopic detection with liquid chromatography.

Details of the projects described in this summary are contained in the semiannual reports submitted by NBS to EPA.

REFERENCE

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DEVELOPMENT OF WATER-RELATED TECHNIQUES AND INSTRUMENTATION: U.S. GEOLOGICAL SURVEY

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INTRODUCTION

The U.S. Geological Survey has been active in environmental monitoring for many years and has furnished assistance in this area to numerous Federal, State, and local agencies. The Survey is a research and hydrologic-data-oriented organization based on strong in-house capability. As part of its monitoring activities, the Survey has taken a lead role in the development, testing, and application of methods, techniques, and instruments for measuring water and water-related constituents and characteristics.

The development of fossil fuel resources in the arid and semi-arid lands of the West has placed new emphasis on improving available measuring techniques and equipment for monitoring water quality and quantity. Indeed, there is probably no area in which it is more difficult to accurately measure the various water-quality and streamflow characteristics for assessing the impacts of mining and related industries. Research to support the monitoring program is concerned with the development of instrumentation for sampling, measuring, and monitoring water pollutants associated with energy-related developments, particularly petrochemicals, toxic substances and sediment, and sediment-laden flows.

This paper summarizes the results and program accomplishments by the U.S. Geological Survey since the inception in 1975 of the Interagency Energy/Environment R&D Program. Activities under the program have been concentrated in four project elements including (1) development of methods for characterizing and monitoring levels of chronic toxicity, (2) development of instrumentation for high-volume analysis of petrochemicals and associated compounds, (3) development of bedload samplers for measuring stream sediment, and (4) development of flumes and weirs and other devices and techniques for measuring sediment-laden stream flows.

PROGRAM DISCUSSION

Development of Methods for Characterizing and Monitoring Levels of Chronic Toxicity

Measurements of response of individual organisms or aquatic communities to potentially toxic substances or mixtures can be used to monitor compliance with standards for protection of aquatic life or to assess changes in quality of natural waters. Transfer of information gained from laboratory bioassays to field situations requires that processes such as equilibration, degradation, and sorption which affect solute concentration of non-conservative toxicants also be evaluated. For example, trace metals tend to adsorb on solid phases in natural waters and thus are distributed differently than dissolved pollutants. In the present study, reservoirs of trace metals for bioaccumulation and physicochemical factors influencing solute metal availability and toxicity are examined. Methods of measuring responses of aquatic organisms and communities to trace contaminants that are applicable to water quality assessment are being developed.

This activity has contributed significant information on distribution and cycling of trace metals in natural aquatic ecosystems. Distributions of solute chromium, copper, iron, lead, manganese and zinc during stratification of a large, oligotrophic lake (Lake Michigan) were examined. Coprecipitation of trace metals with calcium carbonate, adsorption on suspended particulates, such as clays and hydrous metal oxides, and association with organic species are apparently important factors limiting concentration of trace metals in solution. Uptake by plankton in oligotrophic Lake Michigan does not significantly limit solute metal concentration, except in some nearshore areas of high productivity. Factor analysis, a statistical method that takes the explained variance in a correlation matrix and redistributes it among a set of factors to reveal underlying linear combinations of the original variables, is very useful in characterizing physicochemical and biological controls on solute metal concentration.

Seasonal and storm-related variations in solute concentrations of lead, bicarbonate, nitrate, phosphate, and dissolved solids in a small, eutrophic river draining predominately agricultural land were studied. Non-point-source loadings of these constituents associated with individual storm hydrographs can be estimated using a model for predicting unsteady state two-dimensional distributions of solute concentration in natural channels. Solute lead and phosphate concentrations in the river are regulated primarily by sorption to suspended solids.

A major contribution of this study was the development of methods permitting elucidation of the role of physicochemical factors on bioavailability of sediment-bound trace metals. Variations in availability of sediment-bound trace metals to the deposit-feeding, estuarine clam *Macoma balthica* were quantitatively measured for cadmium, cobalt, silver, and zinc. Bioavailability appears to be an inverse function of the strength of metal-sediment binding. Concentrations of zinc in clams (*M. balthica*; *Tapes japonica*) and

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polychaetes (Neanthes succinea; Marphysa sanguinea) from San Francisco Bay are controlled by concentration and physicochemical form of zinc in surface sediments which the animals ingest for food and by species-specific physiological factors. Chemical extraction methods were developed for estimating bioavailability of copper and zinc from natural sediments. Extractions involving complexation and/or mild dissolution procedures best estimate bioavailability. Uptake of zinc by clams increases where iron concentration increases relative to concentrations of other chemical sinks in the surface sediments (that is, as more zinc is partitioned to iron oxide by mass balance effects).

Studies were initiated on the use of embryo-larval, early juvenile bioassays with rainbow trout (Salmo gairdneri) to determine concentrations of trace metals singly and in combination that affect growth and reproduction, the most critical components of population survival. Assays have been conducted with copper, zinc, copper plus zinc, and lead. Zinc and copper are more toxic to late embryonic stages and newly-hatched fry than to early embryonic stages or to juveniles. In contrast, arrest of embryonic development by lead occurs in early embryonic stages. The pattern of toxicity to embryoes may vary significantly between essential and non-essential trace metals.

Development of Instrumentation for High-Volume Analysis of Petrochemicals and Associated Compounds

The upsurge in energy-related activities in recent years has resulted in rapidly intensified water-quality data-gathering activities. The vast numbers of samples collected under these activities have strained the capability of analyzing laboratories, both in terms of meeting the demands and in maintaining acceptable quality of results. The purpose of this project element is to develop the criteria by which laboratory managers can determine the most effective methods and best instruments for analyzing large volumes of samples for petrochemicals and associated compounds.

The approaches are designed to increase instrument output, improve accuracy and precision of analytical results, conserve analytical time, reduce clerical time and errors, and reduce tedium. Specific steps include:

1. Project the distribution of analytical work load. Examine present equipment and work space, and inventory available equipment for automation.

2. Design automated equipment that would maintain or reduce the standard error of estimate on analytical data, double analytical output, and reduce manpower requirements by 25 percent in comparison to that presently required.

3. Define the needed compatibility between command software, input-output of instruments, and data-management procedures for a computer-based control system.

4. Initiate individual contracts to acquire equipment, computer software, and a management system. Initiate contracts for automation of wet chemical extractions, concentration steps, dilution steps, and automatic injectors.

With the contract advice of Lawrence Livermore Laboratory (LLL), it was decided to begin with software and hardware specifications developed for the Central Regional Laboratory, EPA Region V, as well as with other software developed by LLL for other analytical instruments. This would be followed by incorporation into the design of the overall system of sophisticated, computer-integrated instruments now owned by the Geological Survey or commercially available.

Data-handling systems for gas chromatography have been acquired and installed in the Central Laboratories of the Geological Survey. These automated systems inherently are more precise and cover a broader range of concentrations than did former systems. Two gas chromatograph-mass spectrometers (GC-MS) have been purchased and two additional units are planned for acquisition as further automation of organic determinations proceeds. High-pressure liquid chromatography equipment also was purchased and installed. The instrumental capability to perform complex, more sophisticated tests will have been achieved when this equipment and other supplemental equipment is totally operational.

In the final design, two large minicomputers will perform instrumental data acquistion and real time computations, as well as instrumental control. A third minicomputer will process and manage the data accumulated either by the two large minicomputers, from on-line terminals, or from minicomputers dedicated to other analytical instruments, including gas chromatographic spectrometers, gas chromatograph-mass spectrometers, and inductively coupled plasma-jet emission spectrometers. The data management minicomputer, with its on-line terminals, will provide a multi-user time-sharing environment that will provide several computer language capabilities including machine assemblage, BASIC, COBAL, and FORTRAN.

A reassessment of the projected analytical workload distribution indicated that increments of additional analytical support for determining organics in water would be needed in each of the next several years. Definition of the ambient level of petrochemicals found in streams and ground waters and the character of those petrochemicals, particularly those chemicals mentioned in the Toxic Substances Act, should be given priority for improved analytical methodology. For the remaining part of this project activity, emphasis will be on automating sample extractions, phase separations, sample concentrations, and serial dilutions. Requests for bids on contracts to further automate continous extraction procedures and serial dilutions have been issued, and further studies of automation procedures to characterize organics are being conducted.

As the above capabilities are brought on line, the need for a fully automated characterization of organic compounds or compound classes in water samples can be addressed. Attainment of this goal will require several more years, cooperation among many researchers and disciplines, and the continued environmental concern of the public. Assuming that this concern will continue, several fully automated laboratories capable of supplying needed data are now within sight.

Development of Bedload Samplers for Measuring Stream Sediment

Virtually all physical processes involving the removal of mineral resources from the earth's surface, or from underground, disturb the soil mantle, which, in turn, results in changes in surface erosional patterns. At many sites where resources will be mined for energy development, production processes and associated construction very likely will result in increased erosion and delivery of sediment to existing stream channels. The additional sediment burden will significantly affect stream morphology, water quality, and stream ecology. Much of the sediment will be transported in essentially continous contact with the stream bed as bedload. In order to predict the response of the channel and its carrying capacity to changes in the sediment supply so that remedial action can be undertaken to rectify adverse conditions, information must be available on the quantities of sediment transport, particularly the quantities of bedload.

Although a wide variety of direct- and indirect-measuring apparatus has been developed, no sampler or device exists that is universally satisfactory for quantifying bedload transport. The primary deficiency of most apparatus is that sampling efficiencies vary significantly and unpredictably with hydraulic and sedimentologic conditions. Hence, the accuracy of measured data is unknown.

The intent of the research reported herein is to develop one or more samplers for accurately measuring the discharge of bedload in natural streams. This will be done by testing and calibrating existing samplers to define their operating characteristics and efficiencies in sampling different sizes of sediment under various hydraulic conditions. Based on this information, sampler designs will be modified or new samplers will be designed, as required, to provide one or more samplers having stable and predictable sampling efficiencies.

In order to provide the most meaningful results, testing and calibrating will be conducted with full-scale prototype samplers in a 9-foot wide by 6-foot deep laboratory flume capable of conveying discharges up to at least 280 cubic feet per second (7.93 m^3/S). Associated with the flume is a sediment-handling system which has been designed to permit particles, that range in size from about 2 to 64 millimeters and transported as bedload, to be continuously circulated at rates up to approximately 5 pounds per second per foot of width [7.45 (kg/m)/s]. In the calibration facility, sediment moving along the bottom as bedload drops through a slot that extends across the width of the flume at the lower end and falls into one of seven equally spaced weighing pans which are suspended beneath the slot by load cells. When accumulating particles fill a pan, the sediment is dumped through the bottom into a hopper. A screw feed continuously carries the material from the hopper to a solids-handling pump that conveys the water and sediment through piping to the head of the channel and discharges the slurry back into the flow. The load cells that suspend the weight pans are continually monitored as sediment accumulates and the weight of each pan is recorded periodically to permit accurate and essentially continous determination of the bedload transport rate. The monitoring and recording system is entirely automated to permit data processing by computer. The calibration facility is under construction at the University of Minnesota's St. Anthony Falls Hydraulic Laboratory.

A detailed experimental plan for testing an initial complement of samplers has been developed to optimize the number of sampler variations that can be studied during each hydraulic and sedimentologic condition, and to identify as rapidly as possible those sampler features that contribute to stable sampling efficiencies. For the calibrations, the average bedload transport rate obtained from repetitive sampling with a specific sampler will be compared with the long-term transport rate through the width of the flume occupied by the sampler, to define the sampling efficiency for a given sampler configuration.

Initially, versions of the Helley-Smith sampler, which is a pressure-difference sampler in current use, will be tested to determine the effects of various exit-entrance area ratios, width-height entrance ratios, degrees of filling, sample-bag mesh sizes, sample-bag shapes, and sample-bag bottom materials. In addition, the standard VUV sampler, another type of pressure-difference sampler, will be tested as a part of the same series. A bed material mixture having a median particle size of about 10 millimeters will be used in the initial tests. In subsequent tests, the performance of composite samplers incorporating the best features of previously tested samplers will be studied using finer and coarser bed material mixtures.

Ultimately, results from the study will

permit the accurate measurement of bedload discharges under the wide range of conditions encountered in nature, and the availability of such data will facilitate assessments of channel response to the effects of energy-resource developments.

Development of Flumes and Weirs for Measuring Sediment-Laden Streamflow

Conventional methods of measuring streamflow exhibit limited success in the alluvial-channel streams located in the arid west where oil shale and coal development are imminent. Flashy sediment-laden flows of western streams pose extreme measurement and gaging problems. Environmental impacts on surface-water quality of these basins must be based on an accurate and continuous measurement of stream discharge. Present methodology of stream gaging is based on the establishment of a stable stage-discharge relation. At many sites, an artificial control is constructed in the stream channel to provide relatively stable conditions. Artificial controls are of limited usefulness in alluvial channels for the following reasons:

1. Deposition of sediment upstream from control makes accurate measurements of stage difficult.
2. The non-rigid boundary and movable beds of alluvial channels make it difficult to construct an artificial control structure which will remain in place.
3. The relationship between stage and discharge is unstable because of changing approach conditions.

Unique artificial controls have been installed, for field evaluation, at gage sites in alluvial channels in Arizona, Colorado, Kentucky, Utah, and Wyoming. The controls are of five types: (1) dual weirs, (2) supercritical-flow flumes (3) critical-depth flumes, (4) rock-gabion controls, and (5) rock-channel stabilization controls. Each is designed to eliminate sediment deposition in the vincinity of the gage and to provide a relatively stable stage-discharge relation. Data collection under a range of flow conditions will be necessary to assess the effectiveness of the various controls.

Investigation is underway into alternative techniques of measuring streamflow in open channels. Presently three methods of measuring discharge or velocity are being considered, all of which require little or no contact with the water: (1) fluorometric, (2) photographic or video, and (3) microwave.

Fluorometric techniques of streamflow measurement are well established. However, field application of continuous measurement of discharge is limited because of the high-power requirements of presently available fluorometers. Contract negotiations are underway for development of a low-power, sensitive, self-contained fluorometer which can be used for field applications.

The U.S. Geological Survey is preparing a comprehensive report on the feasibility of using photographs or videotape techniques to determine streamflow. The report will include approaches, equipment requirements, techniques for automatic analysis, and recommendations.

Negotiations are underway for a contract to investigate the feasibility of using reflected microwaves to determine surface velocities and stage.

CONCLUSIONS

The U.S. Geological Survey through its participation in the Interagency Energy/Environment R&D Program and other energy-related programs will continue to develop methods, techniques, and instruments for obtaining more accurate water data in energy-resource areas of the Nation. While emphasis has been placed on the arid and semi-arid regions of the West, the developed methodologies will have application in all important energy-resource areas. Due to the nature of the continuing research, final results still are inconclusive but advances in the state-of-the-technology are being made, and improved methodologies will be available in the near future.

STANDARDIZATION AND INTERCALIBRATION TECHNIQUES FOR MARINE MONITORING

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INTRODUCTION

The elements of this project are directed towards developing a capability to define the uncertainties or error boundaries associated with data obtained from environmental measurement systems. The project is composed of two major tasks: Standards Development and Investigations.

Standards development is presently underway in the following specific subtasks: dissolved oxygen laboratory standard; dynamic test apparatus for flow sensors; test specifications for environmental sensors; intercalibration techniques for conductivity/temperature/depth (CTD) and precision pressure sensors; field verification standard for CTD sensors; and a users' guide for underwater optical instrumentation.

Investigations are currently in progress to compare methods for salt water chemical analyses; to compare standards used for in-situ chemical instrumentation to existing analytical standards; and to compare measurement results obtained from water quality "test kits" and specific ion electrodes to results obtained from accepted analytical methods. While all of these tasks are currently active, subsequent discussion will center on those which are nearing completion.

TECHNICAL DISCUSSION

Development of a laboratory dissolved oxygen standard is currently in progress. This standard will serve as a substitute for the Winkler method which is currently used as the reference in the test and calibration of dissolved oxygen measurement systems. The standard will operate in a test bath over a range of -2 to 35 degrees Celsius in temperature and 0 to 40 parts/thousand in salinity. The dissolved oxygen range will span 0 to 15 parts/million with a measurement uncertainty goal of ±0.03 parts/million. By using a submerged sensor, it will be possible to directly monitor oxygen concentration in the test bath. The sensor is similar to the polarographic membrane sensors presently utilized in field instruments except that it is operated in a pulsed mode. With the sensor "off", oxygen crosses the membrane until concentration within the sensor electrolyte equals that of the test bath. The application of a voltage pulse causes oxygen depletion in the electrolyte; the resultant current/time waveform is a function of initial oxygen concentration. The voltage pulse is sufficiently narrow so that the measurement is acquired before oxygen is depleted in the vicinity of the membrane. This results in no oxygen transport across the membrane during the measurement, and, consequently, the uncertainties of the membrane transport characteristics do not affect the oxygen concentration measurement.

The development of a dynamic test apparatus for laboratory testing of flow sensors is nearing completion. The apparatus will generate controlled dynamics superimposed on steady flows to determine measurement capabilities of flow sensors in a nonsteady flow environment. The test apparatus is being designed and fabricated by the Naval Ship Research and Development Center, and will be utilized on one of their tow carriages. It will be capable of two degrees of freedom and provide three modes of nearly sinusoidal dynamics: horizontal, vertical, and circular in a vertical plane. The peak-to-peak amplitudes can be varied from 0.4 to 1.2 meters; the period is adjustable over the range of 2.5 to 12 seconds. The apparatus can accomodate current sensors to a maximum length of 1.8 meters, weighing up to 80 kg. Inducing these motions on the current sensor while the tow carriage is underway provides a simulation of steady current with superimposed fluctuations. This combination of static and dynamic water currents is typical of field conditions where flow sensors are attached as part of a buoyed array. The capability to simulate field conditions will provide more realistic definition of sensor characteristics and limitations.

Transfer standards are utilized to assess the comparability of results obtained between different laboratories performing similar calibrations. A conductivity/temperature/depth (CTD) system has been selected as one of the transfer standard development areas. These three parameters are relevant to most environmental monitoring programs and the calibration process is fairly complex; a capability to perform comparisons is therefore desirable. The measurement goals of the transfer standard are 0.5 to 65 millisiemens/cm in conductivity with an uncertainty of ±5 microsiemens/cm; -3 to 30 degrees Celsius with a ±5 millikelvin uncertainty; and 0 to 1500 decibars in pressure with a ±0.75 decibar uncertainty. An off-shelf CTD system was procured which showed potential for having the high stability required in a transfer standard. Initial measurements have confirmed this stability. The system is presently undergoing a laboratory evaluation over a six month time interval to verify its measurement capabilities. Subsequently, the system will be shipped to another lab for calibration. It will then be returned to the Test and Evaluation Laboratory for final calibration and data analysis. High accuracy pressure sensors is another area in which intercalibration techniques and transfer standards are currently under development. These sensors are now being employed in tide measuring systems and have an accuracy approaching that of the available standards. Pressure sensors have been procured for use as transfer standards and are presently undergoing laboratory testing. Pressure ranges were selected which cover the expected "worst case" measurement areas in the laboratory measurement process. The uncertainty goal for the intercalibration technique is ±0.01% of reading. As with the CTD intercalibration, the pressure transfer standards will be calibrated at a second laboratory, then returned for final calibration and data analysis. The end result for both efforts will be reports which define the transfer standard capabilities and the procedures utilized for performing intercalibration. The measurement results obtained at the two laboratories will be presented as an example of a typical intercalibration experiment.

PROGRAM DISCUSSION

The primary result of all efforts ongoing within the project will be an increased capability to define the quality of environmental data. Energy-related monitoring efforts are decision oriented; these decisions will affect energy exploration and production based on assessment of potential environmental impact. Assessments based on monitoring specific locations over an extended time period or monitoring several locations to develop correlations or models for a larger area require assurance that the measurements can be traced to a common set of standards. There is potential for the environmental data to be treated as evidence in legal actions where environmental damage has been indicated. In this case the data must be defendable--i.e., it must be shown that the measurement process was valid and that the data can be related to accepted standards within defined error boundaries.

The Winkler titration (or a variation thereof) is currently used as a standard in test and calibration of dissolved oxygen sensing systems. The method, however, has demonstrated shortcomings. Simplified, the measurement process consists of sample withdrawal, sample preservation and subsequent titration. Each of these steps is extremely operator-sensitive; it is thus difficult to obtain repeatable data within a lab and extremely difficult to obtain satisfactory agreement between different laboratories performing the same measurements. Past attempts at intercomparison of results have shown variations as high as 20% when a group of well-trained operators each analyzed water samples from a common supply. The approach in developing the dissolved oxygen standard has been to reduce the degree of operator intervention in the measurement process. This will result in a more reproducible measurement process and thus the relation between field measurement of oxygen concentration and the laboratory reference can be defined with more precision.

Measurement of water flow is basic in the development of circulation models which are used to predict transport of energy related pollutants (oil spills, offshore drilling wastes, etc.). Present methods of calibrating water current sensors by determining their output over a range of steady state speeds yield little information on the sensor performance under dynamic conditions. Dynamic conditions, however, represent real-world conditions in the marine environment when the sensor is subjected to motions induced by moorings, turbulence, and wave-generated water motions. These conditions are especially significant in near shore measurements in relatively shallow water. Some initial efforts in the dynamic testing area have indicated that dynamic-induced errors can range from 20% to well over 100%. In attempting to assess the uncertainty levels associated with current measurements, it is therefore necessary to have some knowledge of the dynamic response characteristics of the sensing system.

Calibration of environmental sensors is an area in which standardized procedures have not yet been fully developed. As a consequence, the calibration process tends to vary from one laboratory to another. Even when a common process is generally followed, variations in application tend to arise which have the potential of causing errors in the final result which would vary from lab to lab. In defining the uncertainty of a sensor calibration, which is a component of the overall field data uncertainty, it is necessary to evaluate the total calibration process. This can be accomplished by several laboratories calibrating the same transfer standard - i.e., a known, highly stable sensor - and comparing results to expected values. Two types of problems are addressed in the intercalibration techniques development areas previously discussed. In the CTD area, the calibration process is comparatively lengthy and complex; in addition, results are affected by the adequacy of calibration facilities. The pressure work is directed at a type of sensor whose accuracy approaches that of the available standards. In this case, calibration results are very much dependent on technique. In both areas, the results of the interlaboratory calibrations can be used to evaluate the effect of variations in calibration process and also can be used as a periodic check to verify that the laboratories in question remain in some constant relation to one another.

CONCLUSIONS

At present, none of the subtasks have reached completion; thus, statements of success or failure are somewhat premature. For those areas discussed, however, progress to date has been favorable and indications are that the objectives will be met. The remaining subtasks have not indicated any potential problem areas. Present expectations are that these tasks will be completed without major technical problems arising.

EPA/NASA ENERGY RELATED REMOTE AND IN SITU SENSING INSTRUMENT DEVELOPMENT

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INTRODUCTION

This project was established under the Energy Memorandum of Understanding (MOU) between EPA and NASA dated May 2, 1975, to develop advanced and improved instrument techniques for measuring environmental parameters associated with the generation of electrical energy and other pollution sources.

As a result of the Clean Air Act, many of the large powerplants have been required to burn low sulfur fuels. These fuels are becoming increasingly expensive and more difficult to obtain, and consideration is being given to reverting to fuels with higher sulfur content if the environmental impact is acceptable. Thus, it is important to better characterize the effects of fuel quality (sulfur and ash content) on the local environment. This characterization must include a better understanding of effluent composition, dispersion processes, chemical reactions, and the influence of local meteorology and topography to guide decisions regarding fuel grade acceptability and plant siting, and thus minimize the impact of environmental regulations on our national resources. To achieve this understanding, improved remote and in situ measurement techniques are urgently needed for proper study of stack effluent composition and dispersion processes. In addition to stack effluent measurements, techniques are needed which will be applicable to the measurement of emissions from other types of stationary and mobile sources.

Because of the complexity of the plume characterization problem and the cost of developing advanced remote sensing instrumentation, this cooperative EPA/NASA project consisting of five tasks has been mutually developed to assist in the timely development of the instruments and technology needed in the area of energy-related environmental problems.

OBJECTIVE

The objective of this project is to develop and apply advanced electro-optical techniques to the measurement and characterization of powerplant and other source effluents.

DESCRIPTION OF WORK

To meet the project objectives, five tasks have been identified where additional funding would both complement the NASA research programs and meet specific needs of EPA. A description of each task is given below.

Task 1 - Raman Lidar

The objective of this task is to evaluate Raman lidar for remote measurement of the concentration of SO_2 at a powerplant stack exit. Raman optical radar systems have been developed at NASA and successfully applied in the measurement of water vapor and density profiles in the Earth's atmosphere (ref. 1). More recently, field tests have been conducted wherein the Raman technique was used to detect SO_2 in powerplant stack plumes (ref. 2). Additional modifications and calibration of the lidar system were necessary to make quantitative measurements of SO_2. The modifications included reassembly of the lidar system of reference 2 using a more compact telescope, improvements to the detection and data acquisition systems, and reformulation of data analysis programs (ref. 3). A photograph of the modified system is shown in Figure 1. Also a calibration facility was constructed to calibrate the Raman lidar system for SO_2 and other gases. A schematic and photograph of this facility are shown in Figures 2 and 3, respectively. The 2-meter diameter, 20-meter long calibration tank is charged with the calibration gas which is mixed with air in the tank to a known concentration. Raman lidar measurements are then made through a known volume and concentration of calibration gas. Calibration of the lidar system for SO_2 has been completed, and typical results are shown in Figure 4. The numbers at each point in Figure 4 are the number of laser firings needed to obtain that point with its corresponding precision. Performance of an improved Raman SO_2 lidar is summarized in Table 1. The simulations show that, at a range of 500 meters and night background light levels, a Raman lidar system could measure SO_2 concentrations of 1,000 ppm to within 10 percent with a 1.6-minute measurement time. Complete results from this task are reported in reference 3.

TABLE 1. PERFORMANCE OF IMPROVED RAMAN SO_2 LIDAR

Concentration SO_2	1000 ppm
Range	500 m
Stack Width	10 m
Laser	1 J, 1 pps, 1 mrad
Quantum Efficiency	20 percent
Night Operation	

Receiver Diameter	Precision	Sample Time
8 inches	10 percent	1.6 min
8 inches	1 percent	2.6 hr
24 inches	10 percent	10 sec
24 inches	1 percent	16 min

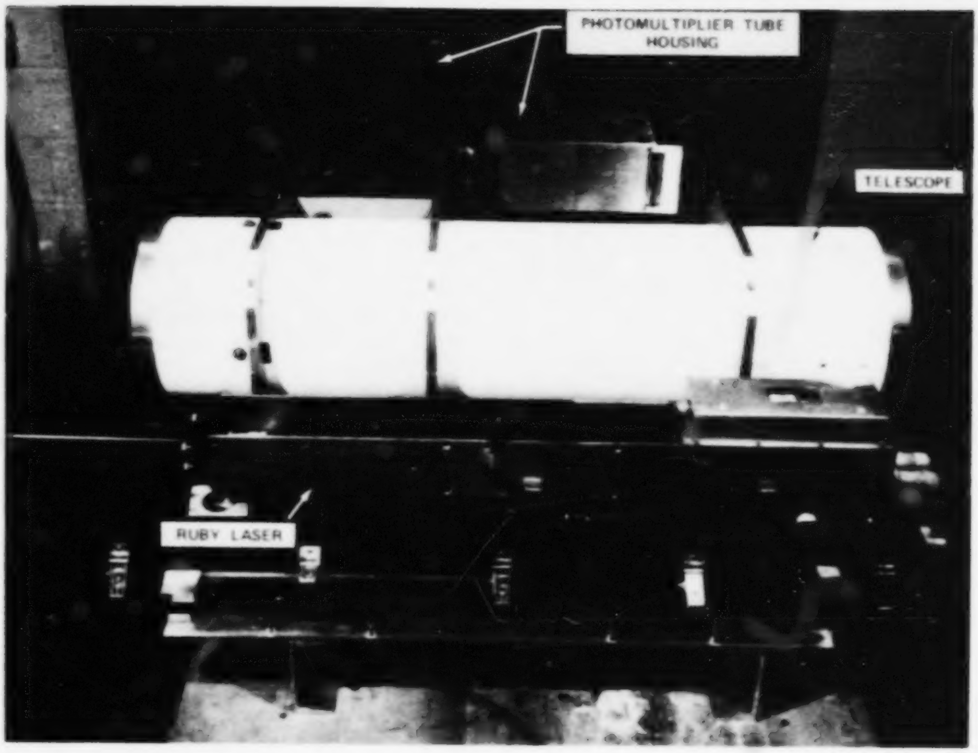
PHOTOMULTIPLIER TUBE HOUSING
TELESCOPE
RUBY LASER

Figure 1.

Photograph of Raman lidar system.

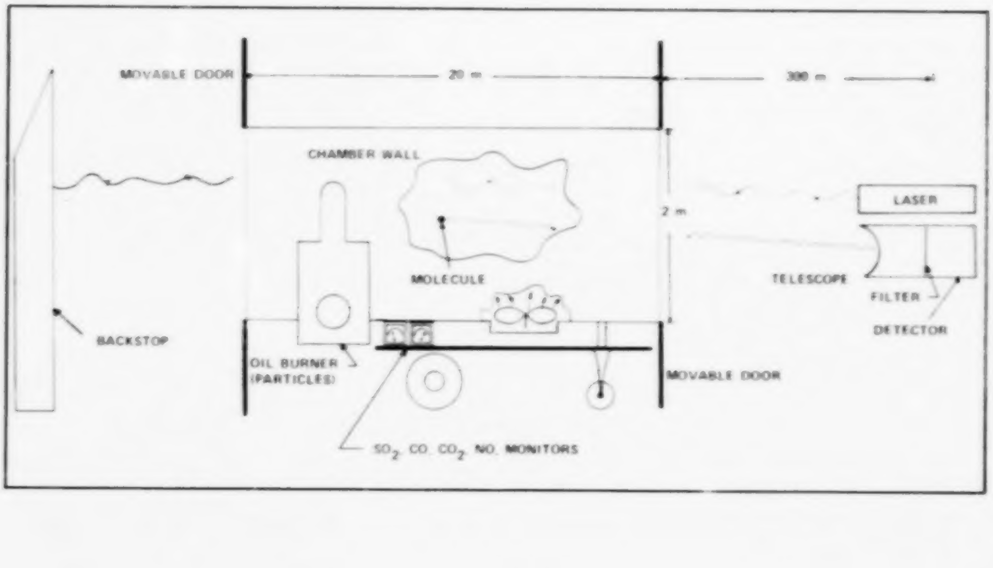
MOVABLE DOOR
20 m
300 m
CHAMBER WALL
2 m
LASER
MOLECULE
TELESCOPE
FILTER
DETECTOR
BACKSTOP
OIL BURNER (PARTICLES)
MOVABLE DOOR
SO2, CO, CO2, NO, MONITORS

Figure 2.

Schematic of lidar calibration facility.

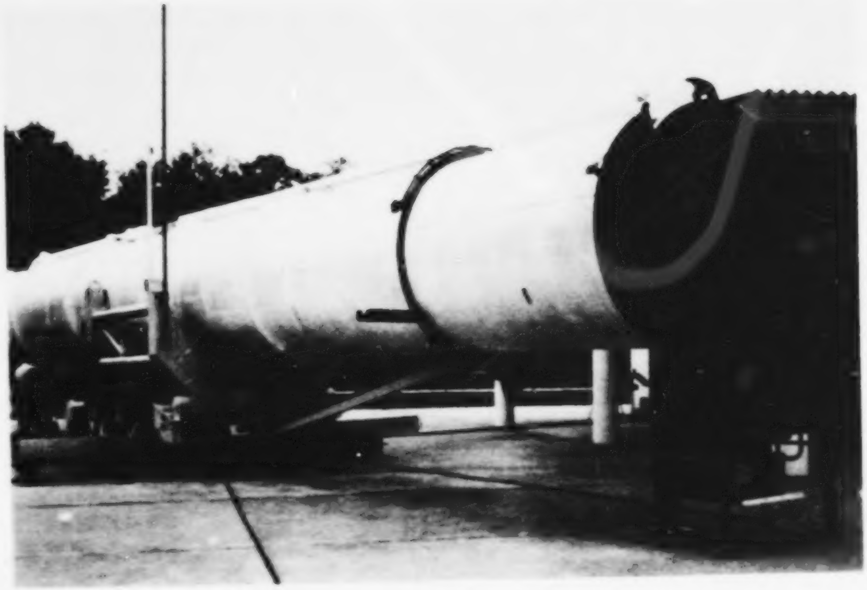

Figure 3.

Photograph of lidar calibration facility.

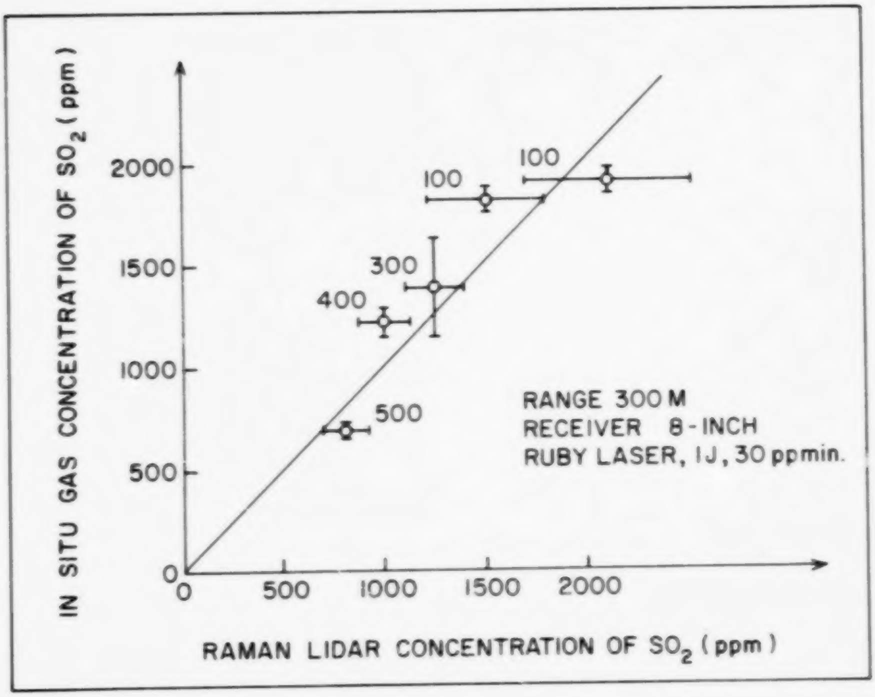

Figure 4.

Comparison of SO_2 Raman lidar measurements with in situ gas analysis

Task 2 - Plume Dispersion Studies

The objective of this task is to apply aerosol scattering lidar techniques to the study of plume dispersion under various atmospheric conditions. NASA has developed lidar techniques for atmospheric measurements and for dispersion studies of plumes from rocket launches (ref. 4). EPA has developed plume dispersion analytical models to be used in studies relative to siting fossil fuel powerplants, and lidar techniques can assist in the experimental validation of these models. Under this task, it was planned that an NASA lidar system suitable for plume dispersion measurements would be assembled on a mobile platform (see Figure 5). With this system, the laser backscatter from particles in the plume would be recorded and displayed to show three-dimensional profiles of the return signal. By averaging the returns over various time scales, the instantaneous and Gaussian aerosol profiles of the plume could be determined as a function of downwind range from the stack. After system checkout and calibration, the system would be used in a joint EPA/NASA field test to study powerplant plume dispersion under various atmospheric conditions, and experimental results would be compared to model predictions. This task was originally scheduled for completion in October 1976; however, no funds were allocated to this task during the second year because of severe budget constraints and work on this task was stopped. F.Y. 1977 funds have been allocated and will be applied to this task, subject to approval by the EPA Project Officer.

Task 3 - IR DIAL

The objective of this task is to develop and apply the tunable infrared (IR) differential absorption lidar (DIAL) technique to the remote measurement of molecular plume effluents. A large number of molecules have absorption lines in the infrared portion of the spectrum. Also, the differential absorption technique, in which a sequential measurement is made first on an absorption line and then at a nearby wavelength off the absorption line (see Figure 6), can provide range-resolved date for particular gases. Thus, the IR DIAL technique has the potential for providing range-resolved concentrations for a wide variety of pollutant species. This task will apply laser technology developed under NSF, ARPA, and NASA sponsorship to construct a DIAL system using a tunable IR laser. A contract has been let for the tunable IR laser, with delivery scheduled for October 1977. After delivery, the laser will be integrated with the IR telescope, detector, and data processor to construct a mobile lidar system. The system will be calibrated using the calibration system described in task 1 and evaluated in joint EPA/NASA field tests at powerplant plumes selected by EPA. This task is scheduled for completion early in C.Y. 1979.

Task 4 - Laser Heterodyne Detector

The objective of this task is to evaluate the use of the laser heterodyne detector technique as a means to increase the sensitivity of long-path, continuous wave absorption measurements using diffuse reflectors. Optical heterodyne techniques have been developed by NASA and successfully applied in solar radiometry and laser communications (refs. 5 and 6). More recently, optical heterodyne techniques have been studied by NASA for atmospheric pollution monitoring from aircraft and satellites in both active and passive modes. These studies show that the use of laser heterodyne detection offers advantages of high spectral resolution, high sensitivity, reduced interference from other pollutants or atmospheric constituents, and vertical resolution of pollutant species (ref. 7). EPA has developed long-path (approx. 600 meters) laser pollution monitoring systems which utilize mirrored reflectors and direct detection of the reflected signal. These systems could have wider application if diffuse reflectors such as mountains or buildings could be used in place of retroreflectors. However, when diffuse reflectors are used in existing systems, the weaker return signal coupled with the relatively low sensitivity of the detector degrades system performance to unacceptable levels. The use of a laser heterodyne detector in the long-path laser monitoring system with diffuse reflectors shows promise of improving performance to levels equal to or better than for a system with mirrored retroreflectors. The purpose of this task is to evaluate the use of a laser heterodyne detector in systems of this type. The evaluation will consist of theoretical studies and laboratory and/or field tests with an NASA-developed laser heterodyne detector such as that shown in Figure 7. An important area of study will be the effects of speckle on the signal-to-noise ratio of the receiver. This task is scheduled for completion in December 1977, at which time a technical report on the evaluation of the laser heterodyne detector will be furnished to EPA.

Task 5 - HCl Monitor

The objective of this task is to develop and deliver to EPA an improved in situ HCl chemiluminescent monitor evaluated at concentrations as low as 5 ppb HCl in ambient and polluted air. In support of its launch vehicle monitoring program, NASA has developed a chemiluminescent HCl monitor which can detect HCl concentrations from 50 ppb to 100 ppm. A photograph of this monitor is shown in Figure 8, and the instrument is described in reference 8. In October 1974, at EPA's request, NASA used this instrument in the Gulf of Mexico to monitor HCl concentrations downwind of an incinerator ship burning chlorinated hydrocarbon waste (ref. 9). Based on the performance of the instrument in measuring HCl concentrations in a combustion plume, EPA felt that, with some refinements, the instrument could provide a much needed technique for measuring ambient HCl levels (>5 ppb). The necessary refinements have been conducted under this task. A laboratory evaluation was conducted of the following parameters of the monitor: accuracy, lower detection limit, response time, lifetime of critical components, and interference (other pollutants) effects. The detector's response to 90 percent of signal ranges from less than a second at 50 parts-per-million to 10 seconds at 1 part-per-million (see response time results in Table 2).

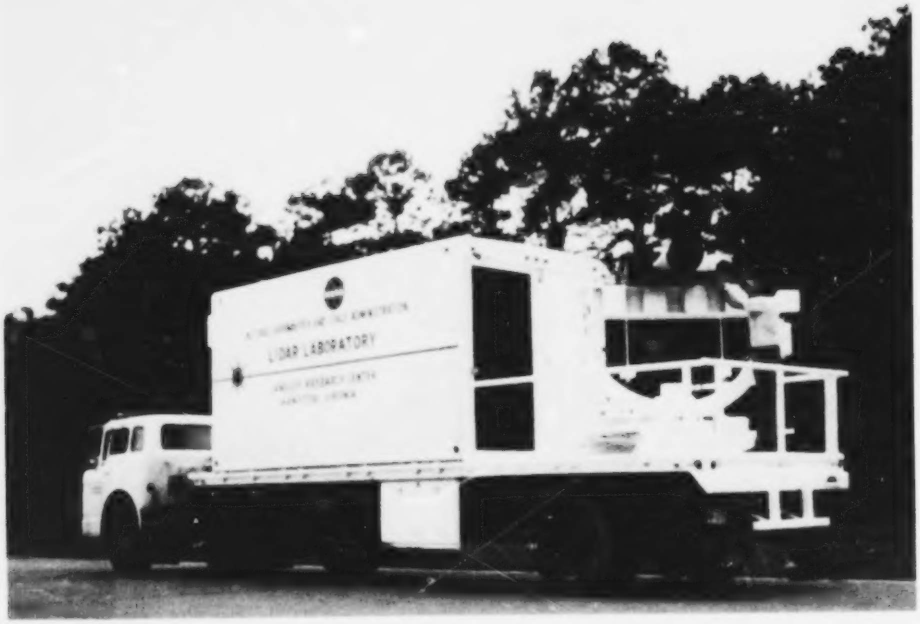
LIDAR LABORATORY

Figure 5.

Photograph of plume dispersion lidar system.

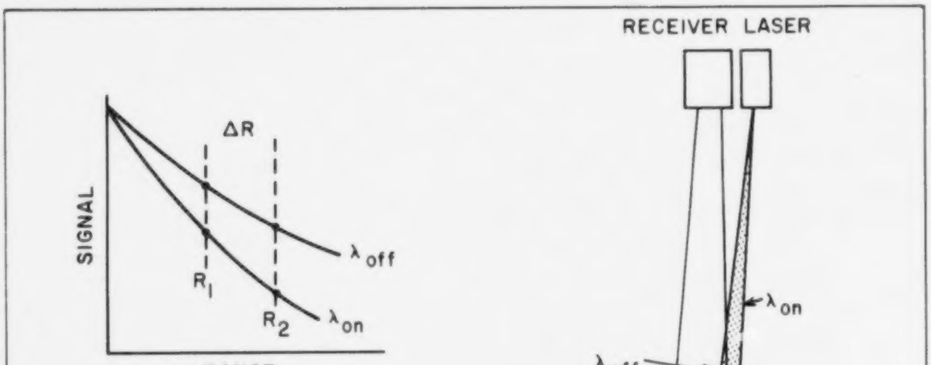
RECEIVER LASER
ΔR
SIGNAL
λ_{off}
R_1
R_2
λ_{on}
RANGE
$N = \frac{\left[\frac{S_{\lambda_{off}} R_1}{S_{\lambda_{on}} R_1}\right]\left[\frac{S_{\lambda_{on}} R_2}{S_{\lambda_{off}} R_2}\right] - 1}{2(\Delta\sigma)(\Delta R)}$
σ
λ_{on}
λ_{off}
CLOUD
EARTH'S SURFACE
λ_{on}
λ_{off}
R_1
ΔR
R_2

Figure 6.

Differential absorption lidar concept.

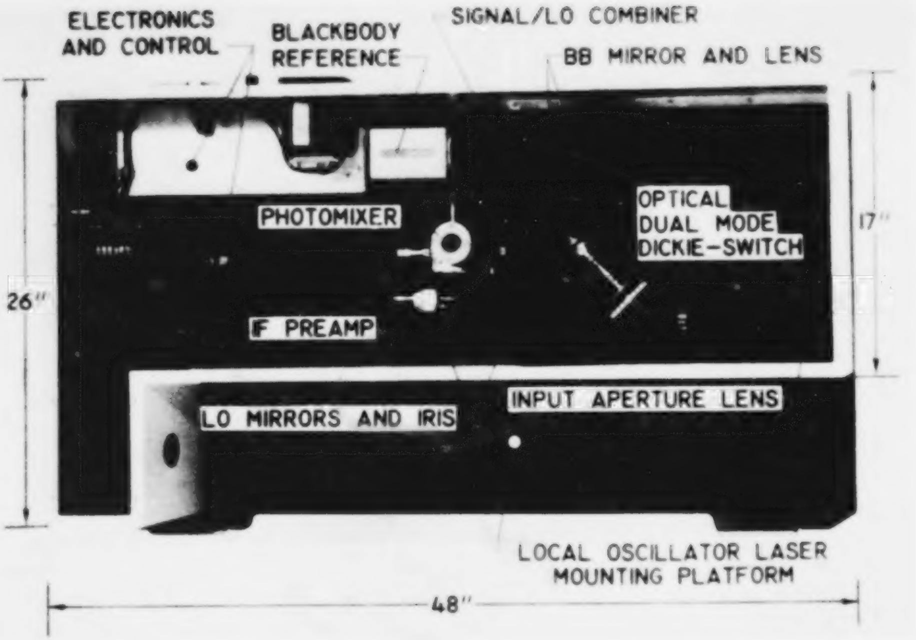
ELECTRONICS AND CONTROL
BLACKBODY REFERENCE
SIGNAL/LO COMBINER
BB MIRROR AND LENS
PHOTOMIXER
OPTICAL DUAL MODE DICKIE-SWITCH
17"
26"
IF PREAMP
INPUT APERTURE LENS
LO MIRRORS AND IRIS
LOCAL OSCILLATOR LASER MOUNTING PLATFORM
48"

Figure 7.

Photograph of laser heterodyne detector.

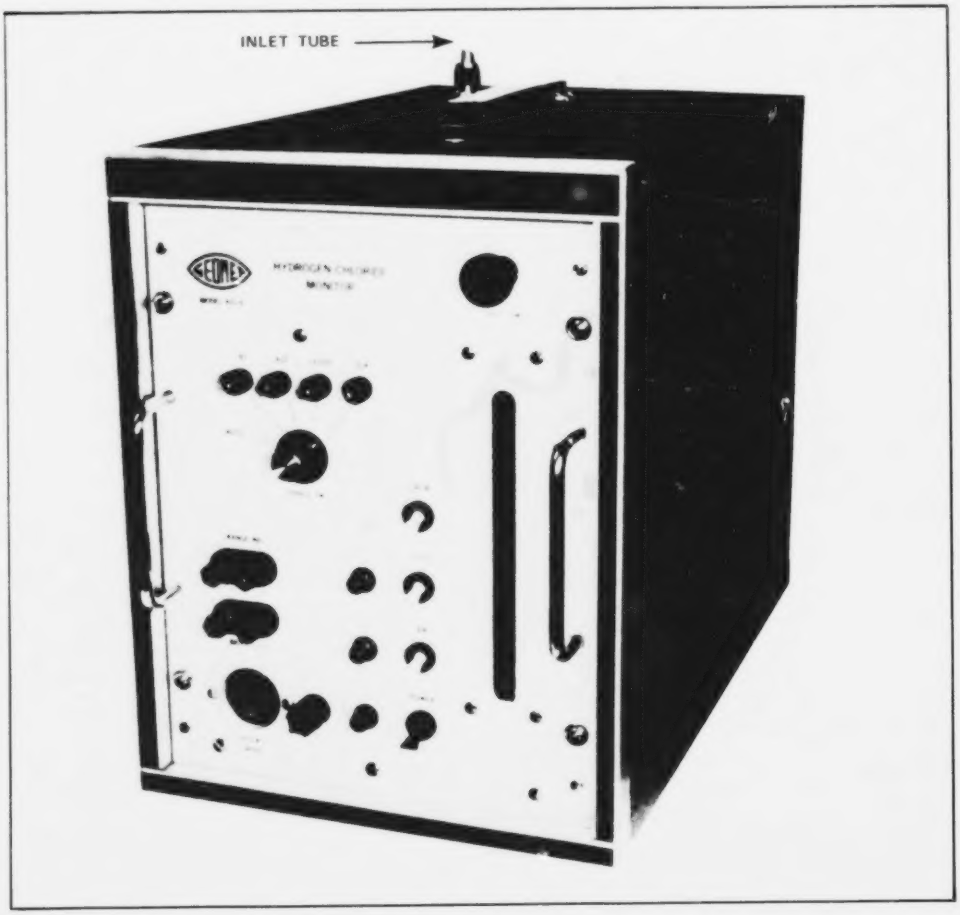

Figure 8.

Photograph of hydrogen chloride monitor.

Below about 50 parts-per-billion, the response is somewhat slower, of the order of several minutes. Several procedures have been developed to improve response time at concentrations below 50 parts-per-billion. These procedures, while inproving response time, result in degradation of other instrument characteristics, and trade-off studies are recommended before these procedures are used. Due to the lack of specificity of the detector, being sensitive to other acid gases, the detector is most suited to studies where hydrogen chloride is the dominant pollutant as compared to the interfering species. The HCl monitor was also evaluated in a variety of field environments, and a liquid HCl calibration procedure was developed for field use. The detector has been in use since 1974 and has been found to be highly portable, rugged, and stable under extreme environmental conditions ranging from aircraft and seacraft operations to desert operations at temperatures above 35°C. All laboratory and field evaluations of the detector have been completed, and the results are reported in reference 10. An improved instrument will be delivered to EPA by the end of F.Y. 1977.

TABLE 2. RESPONSE TIME RESULTS

HCl Concentration	Response to 90 Percent Signal
50 ppm	0.5 sec
20 ppm	1.5 sec
10 ppm	3.0 sec
5 ppm	5.0 sec
1 ppm	10.0 sec
500 ppb	15.0 sec
100 ppb	20.0 sec
50 ppb	30.0 sec
10 ppb	approx 10.0 min
5 ppb	approx 12.0 min

CONCLUDING REMARKS

This paper summarizes the work being done by NASA under the Project Plan for EPA/NASA Energy Related Remote and In Situ Instrument Development. Through this and similar cooperative programs in other fields, a broad range of space technology is being applied to assist in achieving our national goal of energy self-sufficiency with acceptable impact on environmental quality.

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LIDAR TECHNIQUES FOR ANALYZING AND TRACING PARTICULATE POLLUTANTS FROM ENERGY PRODUCTION

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INTRODUCTION

Particulate pollutants from energy-related sources disperse and mix with natural aerosols. Both remote sensing and in-situ identification, measurement and tracing techniques are required for impact assessment, prediction of climate variation and estimation of the character, concentration and dispersion of particulate pollutants arising from man's activities. In-situ sampling may provide specific identification, concentration estimates and size-distributions, but ground and aircraft vehicles cannot economically establish correct average measurements over large periods of time, are impractical for the study of drift, and unfeasible for the measurements of fluctuations. Lidar remote sensors, on the other hand, may be developed, with somewhat diminished accuracy, to identify, measure concentrations and size distributions, and are the economical instrument of choice to measure these quantities and their fluctuations over large volumes and extended time periods. Improvement of lidar techniques is required to increase accuracy of identification, and measurement of size-distribution, shape factors and concentration. Theoretical and experimental investigations of depolarization effects, multi-spectral backscatter and absorption, and inelastic scatter are the most promising technique to achieve the required improvement for measurements from ground and aircraft. The first phase of depolarization field studies and the expansion of the lidar capabilities to two wavelengths have been completed. The depolarization technique has been used in the impact assessment program at Colstrip, Montana to distinguish stack emission from dust newly risen from strip coal mines.

TECHNICAL DISCUSSION

Unique identification of atmospheric aerosols may come from Raman spectra or (broad band) absorption and backscatter spectra, to be investigated later in the study. Severe technical limitations prevent immediate application of these techniques. Identification algorithms, under construction, will use impact data of many kinds to obtain the greatest precision. Identifiers including depolarization effects and multiple-frequency measurements are the first of the more complete series to be used finally.

Radiation backscattered from spherical particles is polarized in the same way as the incident radiation. Depolarization of the backscattered beam can only occur when the scattering particles are non-spherical or when multiple scattering occurs. Thus depolarization is an indicator of departure from sphericity of particles.

The lidar system shown in Figure 1 has been carefully revised to provide accurate measurement of the depolarization of the backscattered radiance. The lidar transmitter, by means of addition polarizing elements inside the cavity, transmits a beam vertically polarized within a few percent. The dual polarization receiver has been constructed to provide the ratio of intensities, to within a few percent, in channels polarized parallel and perpendicular to the transmitted polarization.

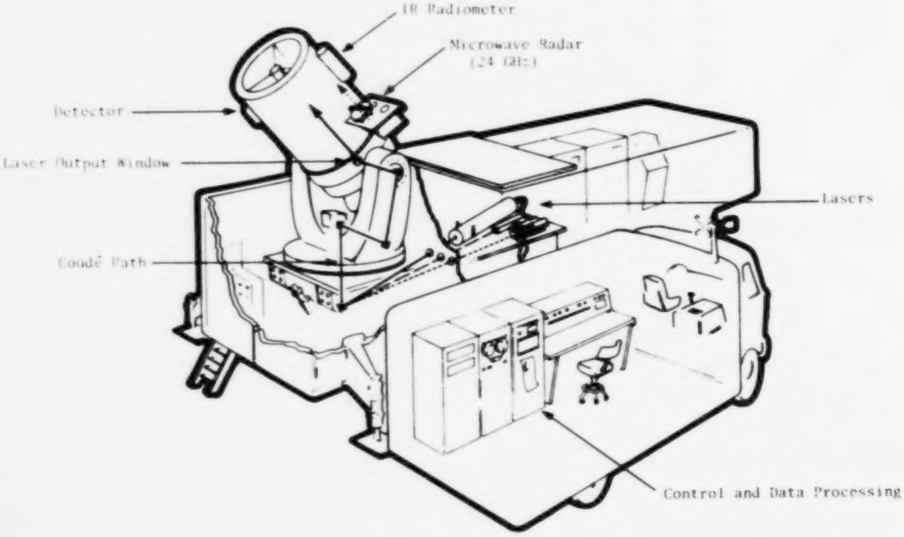

Figure 1. Cut-away view of remote sensing facility.

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The revised polarization-sensitive lidar system has been employed in three major field experiments, examining the depolarization from many kinds of atmospheric particles. As a general rule, with a few exceptions, it has been found that particles from hot sources such as power plants, kilns, and automobiles, are generally spherical, producing very small depolarization. Invariably the non-sphericity of newly-risen dust is indicated by large (> 25%) depolarization. This technique has been employed to separate backscatter from the plume of stack emission in the impact assessment program at Colstrip, Montana, from the backscatter due to dust from the coal mines. This separation permits tracing of the plume without confusion with other sources. Figure 2 shows typical unprocessed data from a single lidar shot with mine dust at 6.8 km from the lidar, and stack emission from the Colstrip power plant at 11 km.

To proceed further in development of particle identifiers, a dual wavelength (.694 and .347 μm) lidar transmitter and detector have been constructed. Theorectical studies have shown that estimates of mean particle diameters may be deduced from multiple wavelength information. The two wavelength system will permit development of field and analytical techniques and the determination of optimum wavelengths and the number of channels required. Particle size estimates and depolarization ratios are powerful identifiers. The ultraviolet wavelength should extend the sensitivity of the system to particle diameters less than .05 μm

PROGRAM DISCUSSION

Two steps have been taken to improve remote detection and measuring methods for particulate pollutants. The first, depolarization techniques, has proven useful in studying plume dispersion in impact assessment programs and in distinguishing plumes from natural background aerosols. Preliminary results on two wavelength techniques have indicated potential for improved identification of particles. Theoretical studies have resulted in improved application of mathematical inversion algorithms to deduce the properties of particles from their electromagnetic signatures.

CONCLUSIONS

The effort to improve particle identification and determination of characteristics has successfully employed depolarization techniques in impact assessment studies at Colstrip, Montana. Initial tests of the dual wavelength system are encouraging for more accurate depolarization, and multiple wavelength studies are now complete. Theoretical studies have supported and directed the evolving techniques.

The immediate future will be occupied with field tests of the depolarization technique and the two wavelength technique. Plans are being formulated for the study of differential absorption and inelastic scatter techniques.

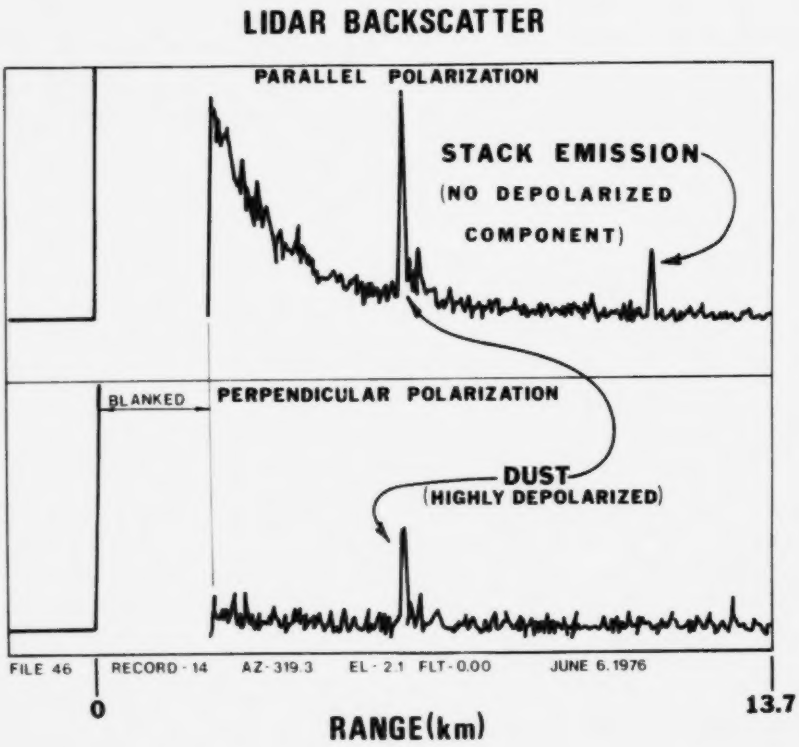

Figure 2. Depolarization of smoke-stack particulates and mine dust.

DOPPLER LIDAR FOR MEASUREMENT OF POLLUTANT TRANSPORT

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INTRODUCTION

There are a number of environmental air quality problems for which Doppler lidar velocity sensing is a useful tool. As introductory material, we will first review operational characteristics of Doppler lidars, typified by the WPL mobile units used in this joint energy research. A brief summary of four problem areas that are being attacked using Doppler lidar measurements will serve to focus the more detailed discussions of progress and applications to follow.

This remote-sensing velocity measurement capability is being applied to four classes of problems in the research program discussed here. In the area of atmospheric diffusion, the lidar is being used to study the profile of mean wind and turbulent intensity at scales smaller than the resolution volume for various meteorological conditions and terrain configurations. For this application, the Doppler system acts as a mobile, high instrumentation tower for wind measurement. Wind characterization is an important part of diffusion experiments if the experimental results are to be applied to other topographic and atmospheric situations.

For measurements of the urban ventilation factor, the wind profile and the height of the mixed layer over the center of the urban area must be frequently measured. Here again the wind tower function of the Doppler lidar to heights of at least 300 m is important. The depth of the mixed layer as revealed by the height at which the concentration of large (>2μm diameter) particles falls off is under study for CO_2 lidar measurement.

In addition to pollutant concentrations, the stack effluent velocity from a stationary source is used to determine the total mass loading of the source. Doppler lidar appears promising for this application, and preliminary checks have been made.

Critical energy installations are subject to a structural wind loading from localized vortex phenomena, such as dust devils, waterspouts, and tornadoes, as well as from the more commonly considered straight-line winds. This project is also involved in a study of dust devils to determine if they provide a wind-loading threat to structures.

The Doppler lidar state-of-the-art in applications before this project is represented by one-time trials of basically laboratory gear. Lawrence et al. (1972) reported on single-point wind measurements at a range of 30 m. Abshire et al. (1974) made similar measurements from hydrometeor targets. Other application tests have not been reported in the open literature, although work tracking aircraft wake vortices has been done on an in-house basis by NASA, and EPA has observed some stack returns using a CO_2 Doppler laser lidar. Work emphasizing lidar development, rather than applications, has been reported in the literature, but it is not relevant to our purpose in this paper.

RESEARCH PROGRESS

Technique Development

Guided by project applications, the infrared Doppler lidar technique is being refined for this research. The technique development is integrated with NOAA's own efforts in the Wave Propagation Laboratory. At this point we are using a compact, mobile Doppler lidar system mounted in a small camper shell on a pickup truck. With a towed, small generator, the unit is completely self-contained and can obtain data while underway. A similar unit has been installed aboard a single-engine Cessna. Its successful operation emphasizes the ruggedness and utility of the basic approach.

The laser, processing optics, and a 30 cm Newtonian transmit-receive telescope are fixed with respect to each other. Appropriate flat mirrors steer the beam anywhere within a full hemisphere in azimuth and elevation, although most work is done between -5° and +18° elevation or at 90° elevation. The range resolution element is determined by the focus of the telescope and is a roughly cylindrical volume less than 0.2 mrad in azimuth and elevation but with a length along the line-of-sight of 10 m at 100 m range. This length increases with the square of the range out to a range where essentially no ranging information is available.

Actual velocity information comes from the line-of-sight component of the motion of aerosol scatterers in the sensing volume. This tracer motion results in a Doppler shift of the backscattered radiation, which is directly interpretable as a velocity using the frequency to velocity conversion of 189 kHz per ms^{-1} velocity component. Since the scatterers are not in general in uniform motion, a frequency (velocity) spectrum is recorded as often as every 16 ms on magnetic tape. From the recorded spectrum, the relative total backscattered energy (0^{th} moment), mean velocity (1^{st} moment), and velocity spread (2^{nd} moment) may be analyzed from each spectrum.

Part of the project is to determine the operating limitations of the system. Work on aerosol statistics (Post and Schwiesow, 1976) has revealed that approximately 5000 scatterers m^{-3} of diameter 2μm and larger are required for a range of 200 m. This corresponds to a typical rural environment with 50 km visibility. The operating range of the lidar in typical urban environments is 1 km because of the enhanced backscatter over rural areas. The clearest environments, such as atop 4250 m Mt.

Evans, lead to a 50% signal dropout rate at 200 m range.

We have established concepts for system improvements to be made during the remaining 3 years of the program. These improvements include offset local oscillator, pulse ranging, and further differential Doppler work. Details of these efforts are given under future plans.

Measurement to Date

Profiles. One- and two-dimensional, single-component wind profiles have been measured for various locations. For these measurements the lidar is either scanned in range for a fixed elevation angle or is scanned in elevation (e.g. 0° to 18°) for a fixed range. Negligible vertical velocity is assumed to allow conversion from line-of-sight to horizontal wind component. This assumption on vertical velocity is weaker at higher elevation angles, so we have operationally limited the elevation to 18°.

We have measured a seabreeze situation with profiles 200 m over the water and 200 m inland using a variable elevation scan. Analysis of the terrain-induced wind modification is underway. A desert wind profile was determined using a fixed elevation scan, which shows an interesting mid-layer shear, as does a fixed elevation scan taken in Denver. Other profiles, using both fixed elevation and fixed range have been taken in a prairie environment under convective conditions, and in various locations near Boulder.

Conclusions from the profile measurements to date include the fact that operational wind profiles are available using a proven field lidar system (although not yet with real-time processing for resulting velocity). Feasibility is demonstrated. This field Doppler lidar unit in its present configuration measures velocity spectra to a range of 1 km and a usable height of 300 m using naturally-occurring aerosols. In contrast to towers, the setup time for a measurement is less than 1 minute. The measurement time for 10-point height resolution is approximately 5 minutes.

Vortices. We have measured the velocity spectra for dust devils, a measurement listed in the project plan, and for waterspouts, which represents additional benefit to this project from other related work. Both phenomena are representative of localized wind phenomena.

Although apparently vigorous because of the unusually large (for the atmosphere) radial accelerations involved, the largest dust devil velocity observed in a two-state field program was 22 ms^{-1} in the horizontal plane (Schwiesow and Cupp, 1976). Waterspout maximum velocities are still under analysis, but the observed spectra are generally similar to dust devil observations.

FM-CW Ranging. Frequency modulation of the continuous-wave CO_2 laser (FM-CW) allows one to determine range to a target by measuring the homodyne frequency difference between the instantaneous transmitted and received signal. We have performed such an experiment, ranging from a hard target (hillside).

A range of 6.8 km gave an easily observed signal with the FM-CW lidar in a breadboard stage. Although this experiment satisfied a project goal, the form of the observed signal spectrum was far from ideal. Rather than occurring at a single frequency, the return from fixed targets is spread significantly in frequency space. This means that it would be difficult, at best, to determine the profile of a distributed (e.g., aerosol) target.

The conclusion of this study is that it is more desirable for operational aerosol profiling purposes to explore some other type of modification to the Doppler lidar. Also, it has proven analytically difficult to separate range and velocity information from an infrared FM-CW return from a moving target. We are therefore pursuing a coherent pulsed lidar technique at 10.6 μm for this continuing project effort.

Three-Component Measurements. We have demonstrated a technique for measuring three components of atmospheric velocity at a single, remote point (Schwiesow *et al*., 1977). The experiment used two pairs of closely-spaced beams in a time-shared mode and a hard target at 30 m range.

This project on pollutant transport includes the goal of measuring profiles of all three components of the wind. The significance of the differential Doppler technique mentioned above is that a new, more effective way of determining all three components of the atmospheric velocity vector is potentially available. The comparative, conventional approach is based on some variation of an azimuth-scanning technique. Azimuth scanning involves an inherent assumption of horizontal homogeneity of the wind field and therefore represents an area average with departures from homogeneity as noise. The differential Doppler approach avoids the need for a homogeneity assumption. It can produce an area average by range and azimuth scanning or by averaging a time history. In the latter case, no mechanical scanning is required to measure all three components.

The present status of the study is that the theoretical analysis of the technique is complete. System design parameters for increased range have been established. Tests on aerosol targets at longer ranges are planned.

Stack and Cooling Tower Plumes. To establish the basic feasibility of stack and cooling tower plume measurements, Doppler lidar tests using the mobile system were performed on actual plumes. The question of signal return is important because liquid water is strongly absorbing at 10.6 μm.

The results of measurements on power plant plumes showed signal-to-noise ratios of 15 db and greater at a range of 500 ±100 m. Signal intensity from the stack varied by more than 10 db over time periods of a few minutes, presumably because of varying burner loads or tube cleaning. These results may not apply to all stacks since the infrared lidar is more sensitive to larger particles (greater than 2 μ diameter) than are the visual aspects of the plume.

APPLICATIONS OF RESULTS

Atmospheric Diffusion

As a result of this study, we have demonstrated that wind and turbulence profiles are measurable using a rapidly-deployed remote sensing system. Knowledge of the boundary-layer wind field allows testing of diffusion models and transfer of results under one set of conditions to another.

With respect to pibal wind measurement, the Doppler lidar should allow increased cost-effectiveness for obtaining micromet wind data for input to diffusion models. This is especially true for problems that require detailed coverage in time and/or area. The lidar provides essentially continuous time coverage of a fixed, rather than drifting, point. With respect to wind-sensing tower instrumentation, the lidar provides greater profile height capability, portability, and cost-effectiveness. As part of this project we have made detailed comparisons between tower and lidar wind measurements, which show correlations greater than .998 for 1 minute averages of the data.

An immediate application of lidar wind data could be to help provide a data base for extension of Pasquill-Gifford type curves for elevated sources and certain types of uneven terrain. Observed wind shear and upper boundary layer acceleration in change-of-terrain seabreeze situations, for example, should allow pollutant transport predictions to be made.

Urban Ventilation

FM-CW (frequency-modulated, continuous-wave) ranging from a hard target with resolution to 10 m has been demonstrated by using a simple modification of NOAA's Doppler lidar system. This approach is potentially applicable to determinations of the aerosol pollution mixing depth.

The infrared lidar is expected to have increased accuracy and cost-effectiveness over airborne in-situ aerosol mixed layer sensing methods because of the general economic advantage of ground-based systems over airborne platforms. Because a lidar measures aerosol profiles directly, it gives the pollution mixing depth rather than the thermal mixed layer inferred from acoustic sounder data. With respect to pulsed visible lidars, the infrared approach offers increased eye safety, freedom from background light, and economy because the same basic unit is also applicable to wind sensing. The infrared depends on the less-numerous larger particles (typically 1-5 μm diameter) for backscatter.

We have demonstrated the ability to measure one-component wind profiles along the mean wind in an urban environment to 1 km range and 200 m height. By increasing the elevation angle from 12° to 18°, the demonstration would be valid for 300 m height if a sufficient aerosol density existed to that height.

In the urban environment, where principal interest is in the lowest part of the atmosphere, the lidar should provide increased height resolution and cost-effectiveness over labor-intensive radiosonde measurements of boundary layer winds. Furthermore, the lidar makes possible increased time frequency coverage of wind profiles with little increase in cost over measurements made a few times daily. Possible effects of severe weather on lidar penetration are not significant for this problem, since under severe weather conditions urban ventilation is not a concern.

Stack Effluent Velocity

We have analyzed the expected Doppler lidar spectrum from a small mean velocity component in the presence of large turbulence for a homodyne (local oscillator frequency equal to the transmitter frequency) system. Because homodyne detection does not reveal the sign of the velocity component, isotropic turbulence folds into a spectrum that obscures a small mean velocity spectral shift. This effect must be considered in interpretation of homodyne lidar results from stacks.

It is obvious that for low elevation angles (small line-of-sight stack velocity component) and large turbulence values, an offset local oscillator or heterodyne lidar is essential to properly interpret the return signal. For cases where the ambient wind is not zero, the sign information from heterodyne processing is extremely helpful in separating ambient and stack velocity effects.

Field experimental stack returns using the present mobile homodyne system have demonstrated the feasibility of stack velocity monitoring with a CO_2 Doppler lidar. This suggests that further study would be profitable.

Vortex Structural Loads

The largest observed dust devil velocities in the experiments discussed in the measurements section of this summary were 22 ms^{-1}. It is fairly obvious without detailed engineering analysis that such winds pose negligible threat to energy-related structures designed for higher straight-line winds.

Although the dust devil measurements represent the conclusion of vortex studies for this joint agency project, studies on waterspouts are continuing under other sponsorship. Should experiments reveal potentially damaging winds in these vortices, the results could be important to the design of energy-related structures. The subvortex structural details inferred from the dust devil data may provide helpful information for tornado models, since photographic evidence of subvortex structure in tornadoes has been suggested by other observers.

STATUS

This research task is two years into a five-year program. Milestones are on schedule. We have made goal revisions, based on research results to date, in two areas. First, new concepts in optical signal processing (differential Doppler) allow transverse wind component measuring research to be an effective replacement for azimuth scanning geometrics for the purpose of 3-component wind profiling. Differential Doppler is also applicable to low-elevation-angle stack velocity measurements. Second, FM-CW ranging has been found difficult to apply to aerosol targets in practice. Progress in digital data handling of high-frequency signals, done elsewhere, suggests that CO_2 laser pulse techniques with coherent detection are a viable method for obtaining aerosol profiles.

By using two existing Doppler lidar systems, we will be able to explore the extension of 3-component velocity sensing by differential Doppler to aerosol targets and longer ranges. Attempts will be made to determine the limiting angular beam separation required for operation and to relate observed signal-to-noise values obtained in the differential case to those seen in the normal pure backscatter geometry. Applications in diffusion, urban ventilation factor determination, and stack effluent velocity sensing should all benefit from progress in this area.

Work on heterodyne Doppler signal processing is designed to give the sign of the line-of-sight velocity component measured by the lidar. This capability is related to diffusion studies, especially vertical velocity measurements, and stack effluent velocity applications.

Various types of digital data processing, beginning with a high-speed clipped correlator, will be studied in an attempt to increase the signal-to-noise and therefore effective range of the system in low-signal conditions. Chances of success in this exploratory research are uncertain.

Coherently detected pulse ranging, without extracting Doppler information, will be attempted for aerosol profile measurements. This work is related to the urban ventilation factor application.

Studies of coherently detected, pulsed Doppler lidar, if successful, would lead to increased range resolution at ranges beyond approximately 500 m. A low duty cycle, pulsed return also opens the possibility of other types of signal processing than we now use. However, within the resource constraints and operational orientation of the project, successful pulsed Doppler experiments are not presented as a working objective.

Field experiments using the Doppler lidar are the basic part of the project. We will continue appropriate feasibility studies to apply our improved understanding and techniques to the measurement of wind profiles for atmospheric diffusion, urban ventilation factor profiles of wind and aerosol loading, and stack effluent velocity profiles.

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AIRBORNE ACTIVE REMOTE SENSING OF POLLUTANTS

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INTRODUCTION

Remote sensing methods appear most desirable in monitoring situations requiring the collection of data over large areas in fairly restrictive time frames. Many applications also arise from difficulties in obtaining access to a particular pollutant. Aerial photography, combined with digital multispectral techniques, remains the mainstay of remote sensing techniques. However, many monitoring problems occur where passive sensing techniques do not provide the degree of specificity needed. Active systems utilizing laser pulses as interrogating probes are being investigated by several groups in the country. Research at the Environmental Monitoring and Support Laboratory (EMSL) in Las Vegas is centered on airborne downlooking active systems.

Three general types of systems are being constructed and evaluated. These are: downward looking LIDARs, devices which range aerosol scattering in the atmosphere; earth-reflected differential absorption devices, used for obtaining concentrations of selected gaseous pollutants; and laserfluorosensors, used for mapping selected water pollutants.

DIFFERENTIAL ABSORPTION DEVICES

One of the goals of many researchers working throughout the country has been that of developing pollutant specific remote monitoring instrumentation. Active systems, those using an interrogating signal, use some sort of differential measurements between laser frequencies. Two different basic classes of instruments are those instruments which use retroflectors and those which use topographic targets or aerosols as reflectors.

A device under study at EMSL-Las Vegas is a system designed to measure ozone from an airborne platform which uses the ground as a reflector. The system has been designed and constructed by EPA and has undergone preliminary flight testing. The operational principles are straightforward. Two lasers are fired sequentially about 15 microseconds (μsecs) apart toward the earth. The short period between the separate laser pulses ensures that the beams hit essentially the same spot on the ground and traverse the same path through the air. The lasers operate in the 10 micron infrared (IR) region with one frequency located on an absorption band of ozone and one just off. Both reflected signals are received with a common telescope and detector, and both lasers are monitored for output power. If the return signals are normalized against their respective power output values, the only essential difference in the return signal will be due to ozone absorption. Note that the device monitors the total amount of ozone beneath the aircraft. To obtain concentrations, some knowledge of the spatial distribution of the ozone is necessary. Results of ground tests confirm a predicted sensitivity of 8 parts/billion ozone concentration over a one kilometer column with little interference from other gases.

The earth-reflected differential absorption device can be used for studies of oxidant and oxidant precursor transport over large areas, measurements which can only be approximated by other methods. The ozone monitoring system can, with several small design changes, be used to monitor selected tracer gases. For example, data collected from a simulated point source plume using a tracer gas could be used as model input information prior to the actual construction of an industrial or power generating complex. Absorption characteristics have been determined in the laboratory. A report is being prepared on the results of the laboratory measurements and the feasibility of using this technique as a viable monitoring method.

The earth-reflected differential absorption techniques can also be used to measure sulfur dioxide (SO_2). The current device would require a very exotic mixture of gases for use in the lasers and thus appears not economically feasible. Ultraviolet (UV) ground-based prototype differential absorption devices have been studied by other groups, and the adaptation to an airborne format seems feasible. A preliminary design for such a device is being completed, and a computer-based model has been constructed for design optimization. The model uses Gaussian plume dispersion parameters and variable device parameters to yield simulated device returns. The output can then be used as input to the various data handling configurations being considered.

AIRBORNE DOWNLOOKING LIDAR

The second type of air pollution monitoring device being developed at EMSL-Las Vegas is the downward looking LIDAR. These devices range aerosol scattering in the atmosphere beneath the plane. They have particular utility in determining plume dispersion characteristics. A prototype system was tested starting in 1974, and test results were used to design and construct an operational system. The operational system uses a flashlamp-pumped dye laser to produce a short pulse of light directed toward the ground. The beam is scattered by molecules within the atmosphere and aerosols and eventually is reflected from the ground itself. A small amount of the reflected and scattered light is received by a telescope/receiver system on board the aircraft and is recorded on digital magnetic tape. In addition, supplemental information including time of day, navigational information, and sequential shot number is recorded on a leader to the LIDAR digital record. The device, together with its real time graphic display capabilities, can be used to measure vertical and horizontal plume dispersion coefficients, plume centerline height, and points of maximum ground-level impact. These parameters, particularly the dispersion coefficients, are usually estimated for modeling purposes, raising the possibility of large errors. Actual measurement of these parameters can considerably improve model accuracy.

A third generation downward looking LIDAR system is currently being assembled. This device will utilize two laser frequencies and be able to differentiate between plumes with different particle size distributions. The device also has much better resolution characteristics than the current dye system. Like the dye system, the two-frequency LIDAR will display the accumulated soundings in real time. The device relies heavily on microcomputer technology, and system component design will allow subsystem utilization in future devices.

Preliminary studies are being made to investigate the feasibility of construction of a downlooking LIDAR that will simultaneously record the scattering from aerosols and nitrogen Raman scattering. The aerosol return will be normalized against the nitrogen Raman return to give a quantitative and reproducible sounding. The device could be used to produce a historical data base on fine particulates in the atmosphere. Routine mappings of the western United States could reveal long-term trends in fine particulate atmospheric burdens.

LASERFLUOROSENSING

Laserfluorosensors are active sensing devices employing UV or visible pulsed lasers to induce fluorescence emission in remote targets, such as pollutants in surface waters. The fluorescence emission is collected by a telescope which is focused on the fluorescent target and then projected by a dispersing system onto a multichannel detector. The resultant signal, which is displayed in real time and is also recorded, can be used either to measure the concentration of a known fluorescent substance or to identify or characterize fluorescent substances of unknown type or origin.

A laserfluorosensor system is currently being evaluated at EMSL-Las Vegas as a means for remotely monitoring the concentration of surface water chlorophyll. The system, presently installed in an EPA Huey helicopter, employs a downlooking pulsed laser operating at 440 nanometers (nm) to excite fluorescence in the chlorophyll-bearing algae present in varying concentrations in all natural surface waters. A small fraction of this fluorescence emission at 685 nm is collected by a telescope receiver which is focused on the laser excitation spot on the water surface. The signal is displayed on a cathode ray tube (CRT), digitized, and recorded on magnetic tape for later analysis. The system has been successfully operated over Lake Mead under full daylight conditions at heights of 1,000 feet. With an average ground speed of 80 feet/second and a laser repetition rate of 1 pulse/second, a profile of 10-foot diameter sampling points is produced approximately 80 feet apart below the aircraft path. By making repeated passes over a chosen body of water, a contour map can be produced corresponding to surface water chlorophyll concentration. For the above-described conditions the system is capable of resolving with good sensitivity surface water chlorophyll concentrations down to 0.1 microgram/liter in the presence of a high solar background.

Concurrent with the airborne measurements, direct sampling measurements of chlorophyll concentration are made by the Department of Biology at the University of Nevada with the purpose of evaluating the performance of the airborne laserfluorosensor, particularly in regions containing large chlorophyll gradients, such as the Las Vegas Bay region of Lake Mead. Good agreement between the relative trends in the airborne and ground truth data has been observed. Presently, investigations of a number of potential interferences, especially those environmental factors affecting the chlorophyll fluorescence quantum efficiency and the effects of changes in transmission of surface waters on the laser excitation and chlorophyll fluorescence emission, are being made.

A second laserfluorosensing program is being conducted with the purpose of developing an airborne sensor able to provide an overall indication of organic pollution in surface waters. A feasibility study has established that a strong correlation exists between Total Organic Carbon (TOC) in surface waters and the intensity of fluorescence emission induced in the same sample by near-ultraviolet radiation. Samples are exposed to UV light and the fluorescence emission monitored using a scanning monochromator-detector combination. The fluorescence arises from trace concentrations of particulate and dissolved organic materials, both man-made and natural in origin, rather than from the water itself, which does not fluoresce. In addition, the water molecule emits an intense Raman band of constant amplitude, which is employed as an internal reference standard with which to normalize the concurrent fluorescence emission. Data from this study will be used to develop an airborne laserfluorosensor capable of mapping surface water total organics. This device will employ a pulsed UV laser to excite fluorescence in surface waters in which the emitted fluorescence and Raman signals will be measured using a telescope coupled by a dispersing system to a multichannel detector and converted to an equivalent surface water TOC value.

CONCLUSIONS AND FUTURE OBJECTIVES

Problem areas encountered during development of the above-mentioned systems have characteristically centered on adapting the commercial lasers for use aboard aircraft. Operating the infrared lasers has been especially difficult, and the structural configuration of these instruments is being changed to produce better isolation between the transmitting laser and the receiver.

Two technical approaches which seem to be yielding greater benefits than anticipated are the potential use of a standard optical mechanical receiver assembly and the incorporation of microprocessor techniques into electronic subsystems. At the present time, it appears that duplicate receiver assemblies to the one developed for the two-frequency LIDAR system will also be used in: 1) an advanced laser fluorosensor system, 2) a proposed UV earth differential absorption system, and 3) a proposed LIDAR system to obtain ratios between molecular and aerosol scattering. The incorporation of a standard receiver into future designs will represent a real savings in resources, development time in particular. A microprocessor development system has evolved over the past two years that now has the capability of programming microcomputer subsystems used in remote sensing devices. Two important advantages of the microprocessor approach to design are: 1) the ability to design systems controllers with very great complexity, and 2) the ability to change design configurations in software as opposed to rewiring subsystems.

The activity in remote sensing instrumentation development at EMSL-Las Vegas can best be described as applied research. Basic research needed for designing the types of devices described within this paper comes for the most part from other organizations, and the devices, whenever feasible, use commercially available components. Operating in this mode requires much supportive research and development from other groups. The strongest reliance on basic research is placed on the many related programs being conducted by NASA.

Future objectives in the design and implementation of remote sensing devices include designs for: 1) an operational downlooking SO_2 monitor, 2) a downlooking LIDAR with limited scan capability, and 3) a LIDAR which simultaneously monitors both aerosol scattering and the Raman return from nitrogen (N_2) molecules, thus yielding quantitative and reproducible scattering measurements. Although the current inventory of active remote sensing instruments is small, applied research programs are responding to the need for this important class of monitoring instrumentation.

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ecological effects

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No Water Skiing
THIS WATER IS A
HEALTH HAZARD
This stream contains harmful
bacteria & viruses. Wash with
soap any part of the body or any
animal that has been in contact
with water
No Scuba Diving
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U.S. Department of Interior

INTRODUCTION

The Interagency Energy/Environment Research and Development Program supports a wide-ranging effort to improve understanding of the ecological impacts of energy development. It encompasses over 50 research projects managed by 6 Federal departments or agencies. It addresses the impacts of various energy technologies as reflected in marine, terrestrial, and freshwater ecosystems. It includes studies as far flung and diverse as those of the impact of an oil spill in the Strait of Magellan, the effects of trace elements from coal utilization in the arid West, and the effects of atmospheric emissions on soybeans and other crops in the Southeastern United States.

Results of many of these individual studies are now beginning to emerge and will provide contributions to our scientific understanding. But, in the final analysis, the more difficult and significant question is, How do we apply these findings to improve decisionmaking—that is, to make more meaningful environmental impact assessments, better environmental standards and regulations, and more informed decisions where environmental/energy trade-offs are involved? We hope to address that question in our discussions this afternoon.

The question is always a difficult one to answer with respect to any research program, particularly in its early stages. Key participants in the ecological effects component of the Interagency Energy-Environment Research and Development Program have maintained a continuing effort to address these questions as a basis for program planning and management. In this regard, I invite attention to the workshop entitled "Environmental Effects of Energy" held in Savannah, Georgia, in December 1976. Research managers and principal investigators reviewed the overall status of their work in relation to many of the issues to be discussed here today. The published Proceedings will soon be available.

Today's panel will discuss some of the basic environmental effects of energy development in terms of the results of selected studies funded through the Program. The 10 papers selected for presentation represent a wide range of agencies, technologies, ecosystems, and research approaches. These papers run the gamut from tightly controlled physiological experiments, through efforts to simulate and understand entire ecosystems, to development and application of improved impact assessment methods. At first, they may seem to encompass a bewildering range of subject matter. But combined, they provide an excellent perspective from which to address some underlying issues in environmental analysis.

There is widespread dissatisfaction with the use of ecological information in decisionmaking and with the current state-of-the-art of impact assessment, or at least the way in which it is practiced. There has been much criticism both of the content of environmental impact statements and of many of the large-scale environmental assessment studies currently underway in response to NEPA requirements and to other legislation. Most recently, the President, in his Environmental Message, has called for more effective environmental impact statements.

ISSUES UNDERLYING ENVIRONMENTAL IMPACT STATEMENTS

These concerns raise two basic questions: (1) How good is our information about ecological effects? (2) How well are we putting existing information into practice? For purposes of today's discussion, I have attempted to identify three issues which underlie these questions.

1. How can we relate the findings of laboratory experimentation, in which the variables can be closely controlled, to actual experience in nature, where many more variables are involved? How, for example, can we base environmental criteria or standards on the results of laboratory toxicity studies?

2. How can we detect and measure environmental change actually occurring in the field, and how can we determine whether it is related to the particular energy development under study? This problem stems from the dynamism and complexity of natural ecosystems and from the fact that they are frequently adjusting to both natural and man-induced stresses. Involved are such difficulties as separating impacts from natural variability, relating observed changes to causes, and assessing the significance of change in terms of major or irreversible ecosystem damage. The problems involved in establishing meaningful environmental baseline and monitoring programs are an example.

3. How can we make the results of ecological research directly useful to the decisionmaker? This involves transfer of technology and conversion of research findings into methodologies and guidelines that can be applied operationally.

We propose to address these three issues as follows: I will summarize very briefly the contents of the papers submitted. Each of these papers will, however, be published in full in the Proceedings of this conference. Next, individual panelists will serve as discussion leaders to address each of the three issues. We hope to stimulate a discussion among all panel members concerning how their work relates to these issues.

In brief, then, the contents of the papers submitted for today's panel are as follows.

1. The first paper, by Dr. Margaret James and Dr. John Bend, is entitled "Xenobiotic Metabolism in Marine Species Exposed to Hydrocarbons" and represents the basic physiological research that provides a fundamental underpinning for more applied efforts to understand the impact of oil pollution on marine ecosystems. It has been demonstrated that most fish species bioconcentrate pollutants, including hydrocarbons, from their environment. The authors have been studying metabolic and toxic effects stemming from uptake of selected components of crude oil in a number of marine species. They have been studying the interactions between enzyme systems and hydrocarbons in ways which may shed light on the question of bioaccumulation of hydrocarbons by marine organisms—a key issue in assessing the effects of oil pollution.

2. The second paper, "Chemical Characterization and Aquatic Bioassays of Energy Development Process Effluents," by Dr. Rodney Skogerboe and his associates, represents another approach to determination of toxic effects of energy development, in this case working with coal, oil-shale, and phosphate developments. Process effluents from energy development programs are frequently complex mixtures of chemical constituents which individually or collectively may be toxic to aquatic biota. Thus, assessment of these effluents in terms of toxicity, identification of the toxic principals, delineation of environmental stability characteristics of these entities, and ultimate development of quantitative impact predictions are complicated research problems of major importance.

To characterize the potential impacts of energy development processes, the present program has utilized chemical and biological assessment methods in a coordinated, feedback mode of operation. Bioassays run on effluents and separated fractions thereof have been used to focus chemical analysis on those of most consequence. Chemical characterization of the toxic fractions has subsequently permitted design of further bioassay experiments indicative of which constituents are the primary toxicants. As chemical and biological assessments of each effluent are completed, the results are used in combination with field evaluation data to develop impact predictions and/or appropriate control strategies.

CHEMICALS IN OFFSHORE WELL DRILLING

3. Dr. Norman Richards has been studying "Effects of Chemicals Used in Offshore Well-Drilling Operations." This project is to provide research results which can help guide regulatory decisions related to offshore drilling in the Gulf of Mexico. Literature concerning the effects on marine organisms of the use of chemicals in offshore well-drilling operations is very limited. A research program on drilling-fluid constituents has been initiated to provide information on the relative hazard of alternative drilling mud constituents and to develop more relevant laboratory methods. Dr. Richards' evaluation paper discusses the hierarchically arranged methodology used for testing the effects of selected chemicals. Tiered screening processes were used for sequential testing of compounds. From the initial set of compounds, two were selected for further study. Static toxicity tests were conducted with larval stages of three marine/estuarine species: eastern oyster, grass shrimp, and pinfish in a laboratory environment. Bioconcentration effects up to 80 times that measured in the exposure water were observed.

MARINE ECOSYSTEMS

4. Dr. Michael Pilson's paper, "The Marine Ecosystems Research Laboratory: A Facility for the Investigation of Effects and Fates of Pollutants," describes an effort to bridge the gap between traditional laboratory experiments and experience in natural systems. At the University of Rhode Island Marine Ecosystems Research Laboratory, a series of tanks simulates environmental conditions typical of coastal ecosystems in the Northeastern United States. Biological (in phytoplankton abundance and species composition) and chemical behavior of these microcosms is similar to that of Narragansett Bay, Rhode Island. Experiments using oil as a pollutant within the tanks are now underway to obtain quantitative information on the effects of low chronic levels of oil on phytoplankton, zooplankton, and benthos.

TERRESTRIAL ECOSYSTEMS

5. In their paper on "Effects of Coal-Fired Power Plant Emissions on Terrestrial Ecosystems," Dr. James Kelly and his colleagues point out that research needed to provide knowledge of ecological effects and impacts of atmospheric emissions should be approached on three levels—the species, the community, and the ecosystem. The objective of research on species is to determine the impact of simulated ground-level concentrations of sulfur dioxide and nitrogen dioxide on the productivity of plants. At the community level, studies will determine effects of emissions from coal-fired power plants on food and fiber crops of economic importance in the Southeastern United States. These efforts will measure the amount of sulfur transferred from the atmosphere to agro-ecosystems and evaluate the economic significance of atmospheric sulfur on crop production. At the ecosystem level small experimental watersheds on the Cumberland Plateau have been chosen because their soil and vegetation complex allows easier detection of positive or negative impact due to the infertile and unbuffered nature of the soil. Ecological data, when combined with economic and sociological considerations, will provide an insight into environmental perturbation.

6. Dr. Philip Filner, in his paper on "Mechanisms of Resistance to Sulfur Dioxide in Green Plants," addresses the potential of reduced agricultural productivity stemming from increased sulfur dioxide levels from a different standpoint. Although green plants are sensitive to acute exposure to sulfur dioxide, the mechanism by which injuries occur is unknown. Using members of the cucumber family as experimental plant species, the mechanisms of injury and resistance to sulfur dioxide were explored. It was found that there are at least two mechanisms by which resistance to acute injury from sulfur dioxide can be achieved. The first is genetically or phylogenetically determined. The second is developmentally controlled resistance which allows young leaves to absorb sulfur dioxide without injury. Dr. Filner's work represents an example of basic physiological and biochemical research with potential application for developing plant strains resistant to air pollution.

FRESHWATER ECOSYSTEMS

7. In a paper on "Methods Development, Field Assessment, and Trophic Relationships of Biological Communities in Freshwater Ecosystems," Dr. John Crossman and his associates present a broad overview of studies being conducted by TVA on the environmental impacts of energy-related technologies on the aquatic environment. Areas of interest include the impact of thermal discharges of power plants on important fish food organisms, concentrating on insect embryo tolerance to

thermal shock; models for planning development of surface mines, considering effect of reclamation on the quality and quantity of local streams, biological impacts of surface mining, and cumulative effects of pollutants from multiple mines; environmental impacts of byproducts from coal combustion and nuclear fission, especially trace metal or radionuclide bioaccumulation in mussels; determination of whether specific design, siting, and operation of intake structures can mitigate effects on zooplankton by reducing the numbers of organisms entrained in the condenser cooling water systems of steam-electric power stations; and development of a computerized information system to accommodate biological data and perform a variety of analytical procedures.

OIL SPILLS ON COASTAL TUNDRA PONDS

8. The paper by Dr. John Hobbie and others on "Effects of Prudhoe Crude Oil Spills on Coastal Tundra Ponds" describes studies on the ecological effects of and recovery from controlled crude oil spills. These show marked changes in species composition and slow recovery to prespill conditions. The rate of oil degradation is slow near the frozen Arctic Ocean, which may increase the exposure time of pond organisms to soluble compounds. In addition, invertebrates living on the surface or emergent vegetation were caught mechanically in the floating oil scum. Multiyear life cycles of arctic macro-organisms near Barrow, Alaska, mean that potential accidents with crude oil could leave long-lasting effects.

ECOSYSTEM CHARACTERIZATION

9. In his paper, "Ecosystem Characterization—An Approach to Coastal Natural Resource Planning and Management," Dr. William Palmisano discusses a technique for providing information on the structure and function of large-scale coastal ecosystems, for use in decisionmaking. Ecosystem characterization is a description of the important components and processes comprised in an ecosystem and an understanding of their important functional relationships. Emphasis is placed on systems understanding through structured integration of information from various physical and biological sciences. The ecosystem characterization involves delineation of the physical boundary of the system, preparation of a conceptual ecosystem model, information synthesis and analysis using the model as a "blueprint," and preparation of a characterization report. Four such coastal ecosystem characterization studies are currently underway—two on the Atlantic coast, one on the Gulf, and one on the Pacific coast.

energy environment II

10. Mr. Robert Hayden, in his paper on "Assessment of Instream Flow Needs," discusses development of improved impact assessment methodology and means of assuring its use in decisionmaking. It has been forecast that energy developments will make extensive demands on water supplies that currently provide habitat for fish and wildlife, including endangered species. There is an important need to improve the capability to predict the quantity of water that must remain in streams to maintain their dependent natural systems. A Cooperative Instream Flow Service Group has been established by the Fish and Wildlife Service to furnish support and assistance to Federal and State agencies developing, testing, and applying methodologies for determining in-stream flow needs. A simulation model that predicts the effects of

altered stream flows has recently been developed. This will be a useful tool for alternative site selection and trade-off evaluation.

SUMMARY

In summary, the information presented in these 10 papers presents an excellent basis for discussing the 3 broad issues raised previously: how to relate laboratory results to natural ecosystems, how to detect and measure environmental change, and how to convert research findings into information that can be used by the decisionmaker. We will now turn to the panelists for a discussion of these issues.

ALLAN HIRSCH

B.S. and M.S., Zoology, Ph.D., Conservation, Michigan State University. As a Fulbright Scholar, went to New Zealand and worked as a pollution officer. Experience includes water resource planning and field studies of water supply and pollution. Has held high positions within EPA, NOAA, and the Federal Water Pollution Control Administration. Presently, Senior Ecologist and Chief, Office of Biological Services, U.S. Fish and Wildlife Service, DOI, Washington, DC.

questions & answers

Dr. Harrison R. Hickey
Tennessee Valley Authority

Mr. Grant Davis
U.S. Forest Service

Mr. Randy Freed
Versar, Inc.

Mr. John Finn
University of Georgia

COMMENT: Dr. Harrison R. Hickey (TVA)

I am going to make an unauthorized comment here. TVA is thinking of having a conference next spring, and what I am hearing this afternoon is so relevant to the theme we are suggesting for this conference, that I think I would have no better opportunity to mention it to the people I hope would be involved. The theme will be environmental effects research used to implement energy systems.

We collectively have to think about packaging this kind of work better so that it gets through to the decision makers involved in supporting programs. There has to be a stronger link between the water-oriented ecological research, particularly freshwater and marine. Part of the reason for the relative absence of water programs in the control technology portion of this effort is probably the domination of air research. As air is the direct contact with humans and human health, perhaps this is justified. However, it does make the linkage between low profile efforts such as aquatic research, ecological research, and related actions that cost a lot of money more difficult. For example, I have read that 3 years of the Alaskan pipeline delay during which costs escalated from $900 million to $8 billion was attributable to debate over the environmental issues involved. How much of that could have been avoided with a good background in ecological effects research, I do not know. But, if some portion of the escalation could have been headed off, it might have been worthwhile.

We think that research on a fish, like a snail darter, might be purely academic until it becomes the key point in whether or not a $100 million dam is built. Delay itself is extremely costly. When we have a nuclear plant scheduled, for instance, we adhere to that schedule like to the Bible because each day's delay costs rather large amounts.

During this coming year I hope we will develop stronger justifications for the relevance of ecological

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effects research for the purpose of building energy systems more expediently and in a manner compatible with the environment.

COMMENT: Mr. Grant Davis (USDA)

Now a few comments on transferring laboratory work into field experiments. One of our major problems, especially in this energy area, is the difficulty in accurately measuring natural changes in the population. For instance, Piceance Basin has a 5,000 acre tract which may be 1 percent of the basin. This could be destroyed completely without anyone noticing an effect on, let us say, the deer population because the deer population cannot be measured to 1 or 5 percent.

We probably should be talking about measuring some of the changes in the habitat potential. We can say that 1 percent of the area was destroyed. Even though this may not be a likely situation, it is a measurable one. Consequently, it may be better to look at habitat potential rather than population changes.

When we talk about chronic changes, we run into an even more difficult problem. A change in the number and in the population of the plant species can be very slow. It is difficult to assess even this impact on the habitat potential of an area. As a result, we may have to fall back on observing the genetic variability of the species of interest. Over a period of time there may be very little effect to those that are adaptable. Some of the mobile populations or even some of the static populations of animals or fish, like deer, the coyote, and the catfish that are very adaptable may be able to adjust over a period of time with the chronic changes; whereas those that have little adaptability, like a trout that has very narrow habitat requirements, may not be able to adjust to the chronic changes.

So, whether we are talking about land or aquatic systems, when we move from the laboratory, where we can control these factors, into the field, we have some difficulty in measuring these changes in the species of interest.

QUESTION:

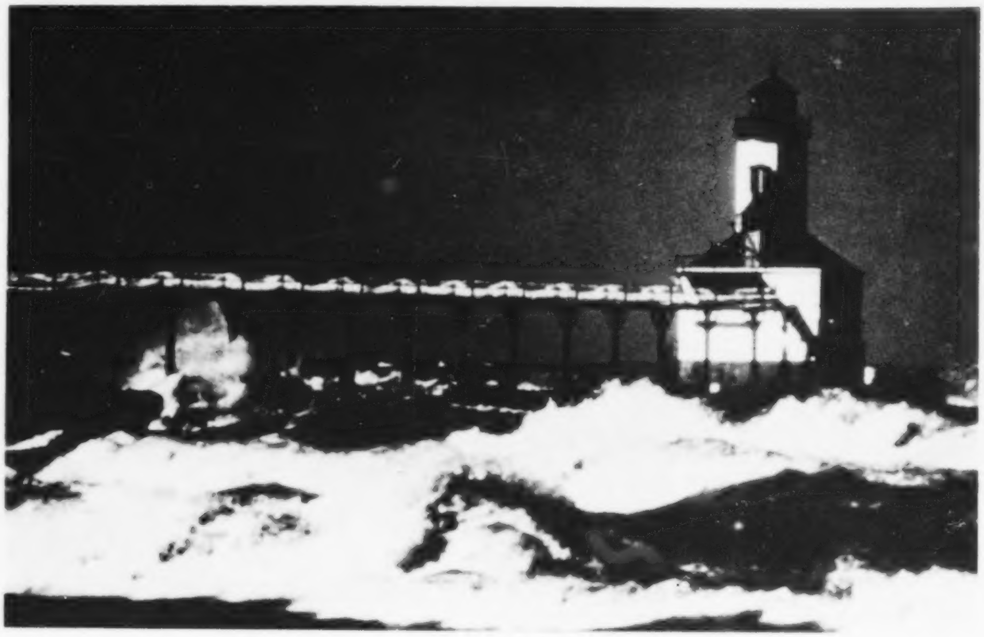
As we have heard today, there are parameters that we can measure when assessing ecological effects. When conveying information to decision makers, what sort of indices do you feel are most synoptic or indicative of changes in ecosystems? Do you think diversity indices would be most synoptic or what?

RESPONSE: Dr. A. William Palmisano (FWS)

The components of ecosystems vary from microscopic organisms all the way up to vertebrates. They are grouped into an assemblage of plants and animals and have functional roles. So, it is the structure related to the function factor in ecosystems which is important.

From the standpoint of the characterizations that we are working on in the Fish and Wildlife Service (FWS), we are looking at conceptual modeling of these systems, stressing those components of systems that are, first, of importance to man directly, such as migratory birds to the FWS fishery resources. Whether it be shellfish or fin fish or other types of natural living resources, such as endangered species or non-game bird populations, the primary criteria is the importance and interest to man. The second criteria that we are using to look at the components of the system are ecosystem function. What is the function of particular organisms? In this case, I am talking primarily about the biological components of the system—what is the function of these components of the system either in (1) causing the maintenance and perpetuation of the natural system, or (2) as they indirectly or directly affect the living resources that man has a particular interest in.

We may put emphasis on the conceptual model and on the characterization itself on a particular organism, for instance a mollusk in a system, because it indicates certain things about nutrient cycling in that system. Or, we may stress the primary productivity of emergent vegetation because we can link that back to ultimate productivity in a system.



This second category of components could be indicators of environmental processes, or could be important support components for higher levels of organisms that we have provided an emphasis. So the deck, so to speak, in a conceptual model is loaded towards those components and processes which we feel are of vital interest to man.

COMMENT: Dr. Allan Hirsch (FWS)

I would like to comment on what to do when the administrator asks you for an anwser. It seems to me that we have the ability to reduce uncertainty, even though we do not have the ability to answer some of these questions in a very specific and certain way. We are dealing with partial knowledge and with uncertain events, and I think it begs the issue to say it is your neck; you are asking for the unanswerable. The researchers who are

engaged in this area, if not the individual researcher, certainly the research managers, have to be willing to extend themselves at least in the area of reducing the uncertainty with which a lot of these decisions are made. I know that some of these decisions are made with information that is far less than what is available at the state-of-the-art. But, it is not enough to throw up our hands and say that there are many things we cannot answer.

The portion of our work that has been described here this afternoon can already help reduce uncertainty somewhat, and I think that is what we need to do.

POLLUTED
WATER
NO SWIMMING
OR WADING

QUESTION:

We have the problem of building models that will answer different types of questions; for example, when we start drilling oil, we release toxicants, we build pipelines, we do a lot of different things to the ecosystem. In your ecological characterization, how can you develop a model that will adequately handle all the different types of impacts that oil and gas development, for instance, will have on a coastal area?

RESPONSE: Dr. Palmisano

You are tangling apples and oranges. The suggestion I made was for us to build natural system models so that we do not focus on an action program, such as, Outer Continental Shelf (OCS) development or setting water quality standards, but focus on natural systems. We develop the boundaries of the system. We develop a conceptual model, at least the state-of-the-art, in interrelating the components of the system. We can use energy flow diagrams to build a model.

But, the point is what is being built? We are building ecosystem models rather than some impact model. We are also building impact models, but those are a specific action program, so we are looking at, for instance, the phases of OCS development, the actions associated with these phases, and then trying to determine what each action has on the resources in the natural systems' characterization.

One model cannot do the whole job; no one data system can do the whole job. My recommendation is that we build modules, system modules, impact modules, data base modules, and that these modules should fit together. No one module will fill the bill.

technical discussion

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XENOBIOTIC METABOLISM IN MARINE SPECIES EXPOSED TO HYDROCARBONS

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INTRODUCTION

In the past few decades, contamination of our oceans with chemical pollutants, including petroleum hydrocarbons, has become a major environmental problem, the latter correlating with increased shipping and drilling operations. Until recently, there have been few studies concerning the uptake, metabolism, distribution, and excretion of foreign chemicals (xenobiotics) in marine species and the possibility of chemical contamination of this important source of human food.

The work of Lee et al (1972a and 1972b) and later Corner et al (1976), Korn et al (1976), Statham et al (1976), and others showed that marine fish, crustacea, mollusca, and zooplankton accumulated hydrocarbons from polluted water, which they could slowly depurate when transferred to clean water. However, few published studies described the metabolism of xenobiotics in any marine species. Since metabolism of a xenobiotic is often a crucial factor in relation to its biological effect and its half life in the animal, we feel it is important to study pathways of xenobiotic metabolism in marine species. We are especially interested in the polycyclic aromatic hydrocarbons, since metabolites of these compounds are known human carcinogens (Heidelburger, 1976). In mammals, hydrocarbons are initially oxidized to alkene or arene oxides in a reaction catalysed by the cytochrome P-450 dependent mono-oxygenases. The alkene or arene oxide may react enzymatically with glutathione, or water, in reactions catalysed by the GSH S-transferases and epoxide hydrase, or may bind to cell macromolecules, or be rearranged non-enzymatically to the alcohol or phenol (Jerina and Daly, 1974). We first determined whether similar pathways of xenobiotic metabolism are used in mammals and in marine species. We then studied the effect of chemical pretreatment of some warm and cold water fish species on the activities of the hepatic enzymes involved in hydrocarbon metabolism, paying particular attention to the polycyclic aromatic hydrocarbons.

TECHNICAL DISCUSSION

Our laboratories are located at the Mount Desert Island Biological Laboratory in Maine and at the Whitney Marine Research Laboratory, University of Florida, St. Augustine. The species used in these studies at each location were caught locally and maintained in fresh flowing seawater until used. They were fed shrimp or small pieces of fish about twice a week. An exception was the spiny lobster, which was shipped from South Florida and maintained in our laboratory for at least 2 weeks before use.

Subcellular fractions of liver, hepatopancreas or extrahepatic organs were prepared as described by Pohl et al (1974). The washed microsomes were resuspended to protein concentrations of about 20 mg/ml and used in assays for cytochrome P-450 content, benzpyrene hydroxylase, benzphetamine N-demethylase, and 7-ethoxycoumarin O-deethylase activities as described in Pohl et al (1974). Microsomal epoxide hydrase and cytosol fraction GSH S-transferase activities were measured essentially as described by James et al (1976). In Maine the optimal conditions for in vitro assay were determined using hepatic microsomes from the little skate, *Raja erinacea*, and in Florida the optimal conditions were determined using hepatic microsomes from the sheepshead, *Archosargus probatocephalus*, and the stingray, *Dasyatis sabina*.

Table 1 shows that cytochrome P-450 was present in liver or hepatopancreas of all marine fish and crustacea studied. However, NADPH-dependent benzpyrene hydroxylase (AHH), benzphetamine N-demethylase, and 7-ethoxycoumarin O-deethylase activities were routinely detected in vitro only in hepatic microsomes from fish species. These NADPH-dependent activities were undetectable or present at the limits of sensitivity of the assays used, in the case of crustacea.

This correlates with what is known of the rate of oxidation of xenobiotics in vivo in fish compared with crustacea. We also found (Table 2) that epoxide metabolizing enzymes were present in liver or hepatopancreas as well as some extrahepatic organs in most of the species studied. Styrene oxide was used as substrate to obtain the results shown in Table 2, but activity towards octene 1, 2-oxide and benzpyrene 4,5-oxide was also measured in most cases (Bend et al 1977). Of special interest was the high epoxide hydrase activity found in hepatopancreas of the crustacean species studied. Since the NADPH dependent oxidation of xenobiotics in these species was low or undetectable by our in vitro assays, we were surprised to find that the products of oxidation were well metabolized by crustacea.

Because they have easily measurable oxidative activities, are readily available and easily maintained, the little skate was used in Maine, and the sheepshead and stingray in Florida to study the effects of chemical pretreatment on xenobiotic metabolizing enzymes. Chemical pretreatment of fish was usually accomplished by i.p. injection of a corn oil suspension or solution of the appropriate xenobiotic, though sometimes the oral route was used. Control fish were treated with corn oil or the solvent vehicle. The day of injection was taken as day one of the experiment.

Table 3 shows the effect of several hydrocarbons and related chemicals on cytochrome P-450

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TABLE 1. CYTOCHROME P-450 CONTENT AND MIXED-FUNCTION OXIDASE ACTIVITIES IN HEPATIC MICROSOMES FROM SEVERAL MARINE SPECIES

SPECIES	CYTOCHROME P-450 CONTENT[1]	BENZPYRENE HYDROXYLASE ACTIVITY[2]	BENZPHETAMINE DEMETHYLASE ACTIVITY[3]	7-ETHOXYCOUMARIN DEETHYLASE ACTIVITY[3]
Atlantic Stingray[4] (*Dasyatis sabina*)	0.43 ± 0.07 (8)[5]	0.86 ± 0.36 (27)	0.98 ± 0.75 (16)	0.05 ± 0.02 (14)
Large Skate[6] (*Raja ocellata*)	0.36 - 0.41	0.30 ± 0.09 (3)	1.49 ± 0.41 (3)	0.47 ± 0.08 (3)
Little Skate[6] (*Raja erinacea*)	0.32 ± 0.08 (4)	0.17 ± 0.10 (10)	1.07 ± 0.19 (9)	0.32 ± 0.14 (11)
Bluntnose Stingray[4] (*Dasyatis sayi*)	0.32 ± 0.12 (3)	0.17 ± 0.05 (3)	0.23 ± 0.11 (3)	0.01, N.D., N.D. (3)[7]
Dogfish Shark[4] (*Squalus acanthias*)	0.23 - 0.29	0.07 ± 0.02 (3)	0.15 ± 0.05 (3)	0.08 ± 0.02 (3)
Sheepshead[4] (*Archosargus probatocephalus*)	0.29 ± 0.12 (13)	1.38 ± 0.47 (9)	1.10 ± 0.42 (9)	0.05 ± 0.03 (9)
Mangrove Snapper[4,8] (*Lutjanus griseus*)	0.25 ± 0.05 (3)	6.64 ± 0.48 (3)	0.88 - 2.50	0.16 ± 0.02 (3)
Winter Flounder[6] (*Pseudopleuronectes americanus*)	0.17 ± 0.01 (3)	2.54 ± 1.67 (7)	0.59 ± 0.13 (3)	0.32 ± 0.25 (6)
Black Drum[4] (*Pogonias cromis*)	0.14 ± 0.03 (4)	1.62 ± 1.91 (11)	0.45 ± 0.09 (5)	0.06
Spiny Lobster (*Panulirus argus*)	0.88 ± 0.52 (15)[5]	N.D. to 0.04 (15)[7]	0.05 ± 0.05 (4)	N.D. (6)
Lobster (*Homarus americanus*)	0.04 - 0.13 (7)[9]	N.D. (3)	--	N.D. (3)
Blue Crab (*Callinectes sapillus*)	N.D. to 0.29 (4)	N.D. to 0.01 (4)	--	---[10]

[1] Nmoles cytochrome P-450/mg protein.

[2] Fluorescence units/min/mg protein. One unit equals the fluorescence intensity of 3 μg quinine sulfate/ml in 0.1 N sulfuric acid (excitation 400 nm, emission 525 nm).

[3] Nmoles product formed/min/mg protein.

[4] Florida species.

[5] Mean ± S.D. (N); range when N = 2; single value when N = 1.

[6] Maine species.

[7] N.D. means no activity detected.

[8] Pools of livers from up to 15 fish were required to obtain enough microsomal protein for assay.

[9] Data from Elmamlouk, T. H., Gessner, T., and Brownie, A. C. 1974. *Comp. Biochem. Physiol.* 48B: 419-425.

[10] Not assayed.

content and AHH activity of hepatic microsomes. In general, chemicals with polyaromatic ring structure induced AHH activity between 5- and 15-fold but there was little effect on the overall cytochrome P-450 content of liver. In many cases, induced fish had higher P-450 content than controls, but differences were not statistically significant and did not correlate with the extent of induction. Other oxygenase activities studied were 7-ethoxycoumarin O-deethylase, which followed the same induction pattern as AHH activity, and benzphetamine N-demethylase activity which was not induced by treatment with the chemicals studied.

The effect of various doses of 3-methylcholanthrene on AHH activity in sheepshead is shown in Figure 1. Doses as low as 1 mg/kg induced AHH activity in hepatic microsomes. Figure 2 shows that induction with a single dose of 3-methylcholanthrene of 20 mg/kg caused hepatic microsomeal AHH activity to be elevated for at least 63 days after injection. We are currently studying the duration of the induction effect.

Another *in vitro* test which discriminated between control and polyaromatic chemical induced fish was assaying for AHH activity in the presence

TABLE 2.

EPOXIDE HYDRASE AND GLUTATHIONE S-TRANSFERASE ACTIVITIES TOWARDS STYRENE OXIDE IN LIVER OR HEPATOPANCREAS OF SEVERAL MARINE SPECIES

SPECIES[1]	ACTIVITY (nmoles product/min/mg protein) EPOXIDE HYDRASE[2]	 GLUTATHIONE *S*-TRANSFERASE[3]
Teleosts		
Sheepshead	6.1 ± 2.6 (16)[4]	25.5 ± 7.7 (16)
Black Drum	4.7 ± 2.0 (13)	16.1 ± 5.2 (13)
Winter Flounder	2.0 ± 1.4 (4)	4.9 ± 0.7 (3)
Eel (*Anguilla rostrata*)	1.4 - 1.5	14.6 - 15.0
Mangrove Snapper	2.5, 1.6[5]	4.2 ± 0.8 (4 pools)[6]
Southern Flounder (*Paralichthys lethostigma*)	2.1 - 2.7	2.6 - 6.6
Elasmobranchs		
Atlantic Stingray	5.8 ± 2.3 (10)	5.1 ± 1.6 (8)
Dogfish Shark	7.6 ± 2.4 (4)	14.6 ± 4.1 (3)
Little Skate	0.14 ± 0.06 (3)	2.4 ± 0.5 (17)
Noose Shark (*Ginglymostoma cirratum*)	7.5 ± 2.8 (3)	6.0 - 12.1
Crustacean		
Spiny Lobster	23.4 ± 4.4 (8)	1.1 ± 0.3 (8)
Blue Crab	7.5 ± 3.2 (3)	0.4 ± 0.3 (3)
Rock Crab (*Cancer ittorus*)	3.2 ± 2.3 (5)	0.3 ± 0.1 (3)
Lobster	21.9 ± 2.4 (4)	1.7 ± 1.1 (3)
Invertebrates		
Clam (*Mya arenaria*)	10.0[7]	0.6[7]
Quahaug (*Mercenaria campechienius*)	0.1[7]	0.7[7]
Mussel (*Mytilus edulis*)	0.3[7]	0.7[7]

[1] Where generic names are not given, see Table 1.

[2] Activity of the microsomal fraction, assayed using 1 mM styrene oxide.

[3] Activity of the cytosol fraction (176,000*g* supernatant), assayed using 1 mM styrene oxide and 10 mM glutathione.

[4] Mean ± S.D. (n): range where n = 2 single value when rate was determined from a single tissue pool.

[5] Pools of livers from 12 and 15 snappers were required to obtain sufficient microsomal protein for assay.

[6] Pools of livers from 6 to 8 snappers were used.

[7] The mean (containing digestive tract and egg masses) from 12 mussels, clams, or quahaugs was pooled prior to homogenization.

TABLE 3. HEPATIC OXIDATIVE ENZYMES OF SOME MARINE FISH AFTER PRETREATMENT WITH HYDROCARBONS AND RELATED CHEMICALS

CHEMICAL	FISH SPECIES (Dose, Route)	BENZPYRENE HYDROXYLASE ACTIVITY (F.U./min/mg protein) CONTROL	BENZPYRENE HYDROXYLASE ACTIVITY (F.U./min/mg protein) TREATED	CYTOCHROME P-450 CONTENT (nmole/mg protein) CONTROL	CYTOCHROME P-450 CONTENT (nmole/mg protein) TREATED
3-Methylcholanthrene	Sheepshead[1] (20 mg/kg, i.p.)	1.4 ± 0.5[2] (9)	10.5 ± 3.0 (6)	0.23 ± 0.12 (9)	0.20 ± 0.09 (6)
	Stingray[3] (3 x 20 mg/kg, i.p.)	0.6 ± 0.2 (9)	0.6 ± 0.1 (6)	0.43 ± 0.07 (9)	0.34 ± 0.06 (6)
	Little skate (2 x 50 mg/kg, oral)	0.8 ± 0.3 (6)	6.5 ± 0.2 (6)	0.24 ± 0.04 (6)	0.25 ± 0.06 (6)
Dibenz(a,h)anthracene	Sheepshead (2 x 10 mg/kg, i.p.)	1.1 ± 0.3 (3)	13.4 ± 1.6 (5)	0.23 ± 0.06 (3)	0.27 ± 0.03 (6)
5,6-Benzoflavone	Sheepshead (50 mg/kg,i.p.)	2.9 ± 1.1 (3)	14.4 ± 6.6 (5)	0.36 ± 0.14 (3)	0.28 ± 0.07 (5)
Hexadecane	Sheepshead (2 x 20 mg/kg, i.p.)	1.8 ± 1.1 (5)	2.3 ± 1.6 (5)	0.21 ± 0.06 (5)	0.15 ± 0.09 (5)
Arochlor 1254	Sheepshead (100 mg/kg, i.p.)	3.3 ± 1.5 (4)	18.1 ± 5.0 (4)	0.22 ± 0.07 (4)	0.42 ± 0.19 (4)
TCDD	Little skate (2 x 4.5 μg/kg, i.p.)	1.2 ± 0.4 (6)	22.7 ± 11.0 (3)	0.24 ± 0.04 (6)	0.34 ± 0.14 (3)

[1] Activities shown are mean ± S.D. for (n) individual fish.

[2] *Archosargus probatocephalus*

[3] *Dasyatis sabina*

[4] *Raja erinacea*

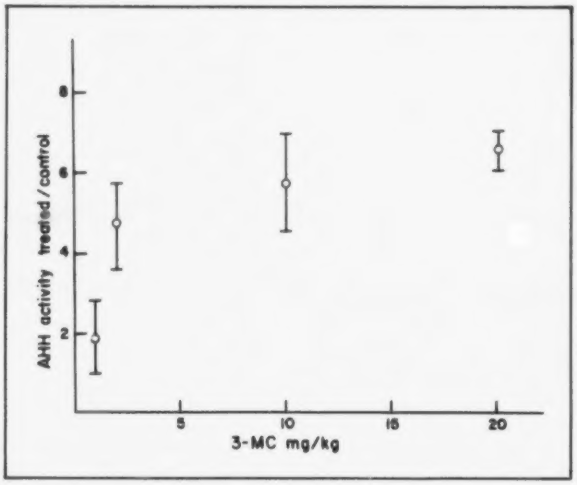

Figure 1. Dose-response of AHH induction in sheepshead. AHH activity (F.U./min/mg protein) was measured in hepatic microsomes from sheepshead which had been injected i.p. on day 1 with a single dose of 3-methylcholanthrene (3-MC) in corn oil at the doses indicated, and sacrificed on day 8. Controls received equivalent volumes of corn oil. Values shown are mean ± S.D. (n = 3 to 8 individuals).

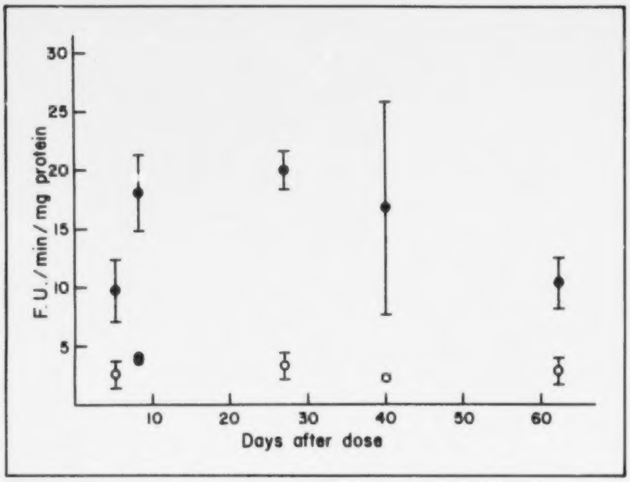

Figure 2. Time course of 3-MC Induction in Sheepshead Liver

• Sheepshead were injected i.p. with a single dose of 3-methylcholanthrene (3-MC) in corn oil on day 1 and sacrificed in groups of 3 to 5 at the times shown. AHH activities (F.U./min/mg protein) were measured in hepatic microsomes. Results are mean ± S.D.
• Sheepshead were injected i.p. with corn oil on day 1 to serve as controls.

and absence of 7,8-benzoflavone (Weibel and Gelboin, 1975). AHH activity in microsomes from induced fish was supressed by addition of 7,8-benzoflavone to the incubation tube, whereas AHH activity in microsomes from control fish was stimulated by *in vitro* addition of 7,8-benzoflavone, (Table 4). Using this test we have found that a few fish caught near St. Augustine, FL, had induced microsomal AHH activity, presumably due to environmental exposure to inducing agents.

Induction of AHH activity is a measure of the capacity for increased production of arene oxides after exposure to aromatic hydrocarbons. Thus the effect of chemicals which induce AHH activity on the epoxide metabolizing enzymes may influence the overall toxicity of the hydrocarbons or related chemical. Table 5 shows that none of the chemicals studied so far had any effect on epoxide hydrase or glutathione S-transferase in the sheepshead, stingray, or skate.

Some *in vivo* studies have been undertaken by Dr. R. Weatherby in our laboratory to determine the persistence of some of the hydrocarbon components of crude oil in marine species. We have found that octane and hexadecane are stored in the hepatopancreas of the spiny lobster for several weeks after a single intravascular dose of 10 mg/kg (Table 6). The slow elimination of these chemicals in the lobster correlates with the very low rate of oxidative metabolism as measured *in vitro*. Similar results were found with Maine lobsters dosed with hexadecane (Foweman *et al* 1976).

PROGRAM DISCUSSION

It is apparent from the data in Tables 1 to 5 and Figures 1 and 2 that considerable individual variation is found in the activities of xenobiotic metabolizing enzymes in the "wild" species studied.

TABLE 4.

EFFECT OF IN VITRO ADDITION OF α-NAPHTHOFLAVONE ON HEPATIC MICROSOMAL BENZPYRENE HYDROXYLASE ACTIVITY IN INDUCED AND NON-INDUCED FISH

CONCENTRATION OF α-NAPHTHOFLAVONE IN INCUBATION TUBE	BENZPYRENE HYDROXYLASE ACTIVITY (F.U./min/mg protein)			
	SHEEPSHEAD		SKATE	
	CONTROL	3-MC TREATED[1]	CONTROL	DBA TREATED[2]
0	1.37[3]	22.6	0.23	5.23
10^{-7}	1.68	22.1	0.23	5.08
10^{-6}	1.72	24.1	0.24	3.88
10^{-5}	2.66	19.8	0.21	3.30
10^{-4}	5.05	8.6	0.73	1.16
10^{-3}	6.05	8.3	0.64	0.79

[1] Sheepshead were injected i.p. with a corn oil suspension of 3-methylcholanthrene (20 mg/kg) on day 1 and sacrificed on day 9.

[2] Skates were injected i.p. with a corn oil suspension of dibenz(a,h)anthracene on days 1, 2, and 3 and sacrificed on day 10.

[3] Results shown are from single experiments for each species. The experiments were repeated three times with similar results.

TABLE 5. EFFECT OF CHEMICAL TREATMENT OF SOME MARINE FISH ON THEIR HEPATIC EPOXIDE-METABOLIZING ENZYMES

		EPOXIDE HYDRASE ACTIVITY[1] nmoles/min/mg protein		GSH S-TRANSFERASE ACTIVITY[2] nmoles/min/mg protein	
SPECIES	CHEMICAL	CONTROL	TREATED	CONTROL	TREATED
Sheepshead	3-Methylcholanthrene (2 x 20 mg/kg, i.p.) days 1 and 3, sacrificed day 6	6.5 ± 4.0[3] (9)	5.8 ± 2.2 (6)	34.3 ± 8.3 (9)	27.5 ± 8.2 (6)
	Dibenz(a,h)anthracene (2 x 10 mg/kg, i.p.) days 1 and 3, sacrificed day 6	6.6 ± 1.9 (7)	4.7 ± 1.3 (9)	15.5 ± 0.8 (7)	14.8 ± 2.5 (9)
	5,6-Benzoflavone (100 mg/kg, i.p) day 1, sacrificed day 5	3.7 ± 1.2 (5)	4.2 ± 1.8 (5)	19.3 ± 5.4 (5)	20.0 ± 2.2 (5)
	Arochlor 1254 (100 mg/kg, i.p.) day 1, sacrificed day 7	3.8 ± 1.8 (6)	4.9 ± 1.6 (8)	18.8 ± 2.8 (6)	20.3 ± 4.0 (8)
	Hexadecane (2 x 20 mg/kg, i.p.) days 1 and 3, sacrificed day 5	2.9 ± 0.5 (3)	3.0 ± 0.4 (5)	15.3 ± 3.5 (3)	14.0 ± 2.5 (5)
Stingray	3-Methylcholanthrene (3 x 20 mg/kg, i.p.) days 1, 4 and 8, sacrificed day 18	5.8 ± 2.3 (7)	4.5 ± 0.5 (4)	6.7 ± 1.5 (9)	5.7 ± 0.6 (5)
Skate	TCDD (2 x 4.5 μg/kg, i.p.) days 1 and 3, sacrificed day 12	0.30 ± 0.12 (6)	0.36 ± 0.14 (5)	2.84 ± 0.23 (6)	2.68 ± 0.12 (5)

[1] Assayed in microsomes: 1 mM styrene oxide substrate.

[2] Assayed in cytosol fraction: 1 mM styrene oxide and 10 mM glutathione substrates.

[3] Mean ± S.D. (n).

TABLE 6.

PERSISTENCE OF [^{14}C]-HEXADECANE AND [^{14}C]-OCTANE IN HEPATOPANCREAS OF THE SPINY LOBSTER, Panulirus argus, AFTER INTRAVASCULAR ADMINISTRATION

	% [^{14}C] REMAINING IN SPINY LOBSTER			
	OCTANE[1]		HEXADECANE[1]	
DAYS AFTER ADMINISTRATION	HEPATOPANCREAS	TOTAL RECOVERY[2]	HEPATOPANCREAS	TOTAL RECOVERY[2]
1	73.4 ± 18.1	83.8 ± 19.0 (5)[3]	53.6 ± 9.9	68.0 ± 9.1 (4)
2	40.2 ± 26.0	51.9 ± 24.0 (5)	62.8 ± 6.1	75.5 ± 6.0 (4)
3	39.0 ± 11.5	47.2 ± 9.8 (4)	58.5 ± 9.3	69.5 ± 8.2 (3)
8	--[4]	--	48.9 ± 3.2	58.7 ± 3.2 (4)
14	18.5 ± 12.6	23.5 ± 13.6 (6)	--	--
21	--	--	33.1 ± 5.3	43.2 ± 3.7 (3)
28	7.4 ± 2.0	11.0 ± 2.9 (3)	--	--
56	--	--	16.2 ± 8.7	20.7 ± 9.1 (3)

[1] An Emulphor solution of octane or hexadecane containing 10 mg/kg + 10 μCi/kg was injected into the pericardial sinus of each animal.

[2] Other tissues counted were: green gland, tail muscle, stomach, intestine, intestinal contents, plasma, gonads, brain.

[3] Results shown are mean ± S.D. (n)

[4] This time point was not studied.

The influence of factors in the physical environment, such as temperature, salinity, and water flow rate, on xenobiotic metabolism has not yet been established, but may be expected to play an important role.

We have demonstrated that exposure to certain chemicals has a long-lasting influence on AHH activity in the sheepshead, and it is probable that the effects of chemicals may be further influenced by the physical factors mentioned. The long term effects of induction of hepatic xenobiotic metabolizing enzymes in fish species (or humans) is as yet undetermined. We do not know whether toxic metabolites of hydrocarbons and related chemicals are stored in edible fish, but it is clear that exposure of certain fish to these chemicals has a biological effect long after the fish has been transferred to clean water.

The *in vitro* addition of 7,8-benzoflavone has proved a valuable tool in determining whether a fish has previously been exposed to pollutants and may be useful in deciding the extent of pollution after an oil spill or accidental chemical pollution. We plan further studies of the *in vivo* metabolism of hydrocarbons in several marine species and hope to develop a pharmacokinetic model for predicting how long different chemicals will persist in a variety of species.

Our studies on the factors affecting induction by chemicals and the mechanism of induction of xenobiotic metabolizing enzymes in marine fish will further our understanding of how biological factors in the animal mediate the toxic and carcinogenic actions of many environmental pollutants.

CONCLUSIONS

Our results, and those of others, have shown that aquatic species are affected by chemical pollutants and may be more sensitive than mammals to the acute lethal effects of a variety of chemicals. In addition, aquatic species may exhibit the biological effects of nonlethal exposure to chemicals more quickly, or at lower doses, than mammals. If this is so, fish would be useful model species for studying the teratogenicity, mutagenicity, or carcinogenicity of certain environmental chemicals. This has already been done in the case of aflatoxin, using the freshwater rainbow trout (Sinnhuber *et al* 1968).

In the past 2 years we have gained a better understanding of how some marine species metabolize foreign chemicals. This should be of predictive value in determining which marine species are most likely to accumulate toxic chemicals and which species are capable of converting chemicals to more toxic substances.

Marine species are an important part of the diets of many people, either directly or in the food chain, and greater knowledge of the interactions between marine species and pollutants is now needed in view of the increasing chemical content of our oceans (Kraybill 1976).

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CHEMICAL CHARACTERIZATION AND AQUATIC BIOASSAYS OF ENERGY DEVELOPMENT PROCESS EFFLUENTS

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INTRODUCTION

In 1975 a research program was jointly undertaken by Montana State and Colorado State Universities to assess the potential effects on the aquatic biota of pollutants resulting from energy development programs in the Rocky Mountain Region. The research is supported by EPA-WQO Research Grant No. R-803950. The program has focused on four areas of energy development: coal mining, coal combustion, coal conversion, and oil shale mining and processing. The major project objectives have been:

1. To establish chemical and biological data bases on potentially impacted streams to serve as reference information for evaluating the ultimate possible effects on water resources and ecosystems due to potential toxicants from associated energy development projects.

2. To determine acute and chronic toxicities to aquatic organisms caused by contaminants resulting from energy development.

3. To identify any toxicants associated with the products and byproducts of energy development processes.

4. To determine the routes of transport of the toxicants from their sources to the aquatic systems and define the mechanistic parameters which define these routes and control the rates of transfer.

5. To synthesize the information from this and other investigations so that estimates of impacts can be made and/or necessary control strategies formulated.

This is clearly a comprehensive and complex undertaking involving research in several areas. A complete discussion of the findings to date or a projection of future research plans is well beyond what can be cogently discussed in the present report. Consequently, a summary of what has been established to date in selected areas of investigation is presented below without emphasizing details. Before doing so, however, it is appropriate to describe the conceptual approaches embodied in the present program and to provide background information on the geological and hydrologic characteristics of the research region.

The effluents from most energy development programs are generally complex mixtures of numerous chemical constituents. To determine the identities of all constituents present, measure their respective concentrations, and attempt to use this information to predict impacts on the aquatic biota would, in most instances, be partially if not monumentally nonproductive. Thus, the approach which was originally formulated and which has been proven successful has been that of utilizing aquatic biota as analytical or screening tools. In essence, acute and chronic bioassays are run on the aqueous effluents and the aqueous extracts of solid products using Daphnia and/or Fathead Minnows. The results of these bioassays are used initially to qualitatively focus on those process effluents or extracts containing toxic constituents which are individually or manifestly operative. Due to the compositional complexity of the majority of such effluents, it has generally been found necessary to subject them to simple, nondestructive separation procedures. The fractions obtained from such separations are of generally simpler compositions and are also subjected to the bioassay screening process to further simplify the chemical identification problem as well as the ultimate assessment of the cause and effect relationships. The utilization of these approaches will be illustrated in following sections. Before proceeding, the general geological characteristics of the Rocky Mountain energy development region, the effects that these have on surface and ground water quality parameters in the area, and how these relate to certain energy development programs deserve discussion.

TECHNICAL DISCUSSION

Large portions of the western coal development region include general stratigraphic features associated with the Upper Cretaceous and Early Tertiary Periods. These formations generally consist of interbedded sandstone, sandy shale, and coal beds of marine brackish water and fresh water origin. The soils, except in alluvial flood plains, are usually thin and poorly developed. The natural vegetation of the region is generally sparse. Because of the geological history of the area, soils and the strata disrupted during strip mining operations are usually quite basic and include fairly large quantities of salts such as gypsum and epsomite. Ground waters in the area are typically quite basic (pH = 7.4-8.2), alkaline (alkalinity = 100-1000 mg $CaCO_3$/l), and exhibit fairly high levels of sulfate (100-1000 mg/L) due to the dissolution of soluble salts. Surface waters reflect these same characteristics; the extensive use of irrigation degrades the water quality of a pristine mountain stream rather rapidly. In effect, the general water quality parameters of the region are such that they exert profound influences on the equilibria associated with the leaching of various normally soluble

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constituents from mine overburden, retorted oil shale, and other energy development products and byproducts.

Coal Mining

The basic nature of the ground waters of the region coupled with their carbonate/bicarbonate buffer capacities are such that very few mine effluents exhibit acidity (pH less than 7.0). These conclusions are based on results of the present investigation involving three different strip coal mines in Colorado and Montana as well as reports by several other agencies and groups. Further, Temple and Kimble (1) have carried out leaching studies on Southeastern Montana core samples which were innoculated with chemoautotrophic bacteria. Although the presence of these bacteria in easily recoverable numbers indicated that they were producing acid, only a small percentage of the core strata studied developed low pH on leaching. The failure to develop acidity even in the presence of the bacteria and the appropriate sulfide minerals was directly associated with the neutralizing capacities of the carbonate minerals present.

In addition, the present studies as well as an extensive examination of water quality data for the region indicate that heavy metal concentrations are typically quite low in comparison to the levels often reported for the acid conditions typical of the Appalachian coal regions. Again, this can be largely attributed to the influence that the hydroxide and carbonate have on the precipitation of several heavy metals. Among the metals having solubilities controlled by these precipitation processes are: Cd, Cu, Fe, Pb, and Zn. In essence, the geological characteristics of the region coupled with the resultant effects on thegeneral water quality parameters are manifested in terms of "benevolent" suppression of the solubilities of several heavy metals which might otherwise prove toxic to the aquatic biota. Although this is a definitely favorable circumstance, it must be emphasized that certain types of processes may have constituents present that enhance the solubilities through complexation, for example, and that several constituents, even though present at low concentrations, may operate synergistically to cause mortalities among the aquatic biota. Thus, the present program has carried out both field and laboratory based studies to evaluate these possibilities.

Field studies on Trout Creek, Colorado, and the Tongue River, Montana, to date have failed to indicate impacts on the aquatic biota due to coal mining that cannot be accounted for by other factors. The field evaluations have shown that the mining operations generally have direct impacts on the gross water quality characteristics of the receiving streams. A general overview of this may be obtained by examination of Figure 1 showing the results of total dissolved solids (TDS) measurements for Trout Creek above and below the mining operation. The TDS levels tend to be fairly low and constant above the mine except during precipitation or thawing periods. The increased TDS levels due to mine drainage may be deduced by comparison of the two curves in Figure 1. During the July-October period, the primary input from the mine is via ground water seepage which approximately doubles the TDS of the stream. The effects of surface runoff and aquifer flushing is indicated by the increases during runoff periods, i.e., a thaw period in December and the spring runoff during March-June. It should be noted that the major spring impact occurred even though the stream flow increased dramatically; dilution did not compensate for the surface and aquifer flushing effect. The field studies have shown that the most significant change in water quality attributable to surface mining is an increase in TDS. The ions making the largest contributions to the dissolved solids content in both mine drainage and receiving waters are calcium, magnesium, sodium, bicarbonate, and sulfate. The compositions of mine drainage and receiving waters are very similar. More than 99 percent of the total load of dissolved solids contributed by the disturbed ground at Trout Creek is accounted for by ground-water runoff. It has been estimated by McWhorter et al. (2) that 2.9 million kilograms of dissolved solids per year are contributed to the stream by the mine which constitutes 17% of the total watershed; this amounts to 54% of the total stream load per year. Of the 15 trace metals studied, only manganese and selenium were observed at levels consistently above those recommended for public consumption. Experiments are now in progress to define whether the higher levels of these elements are significant from either the long term toxicity or bioaccumulation standpoints.

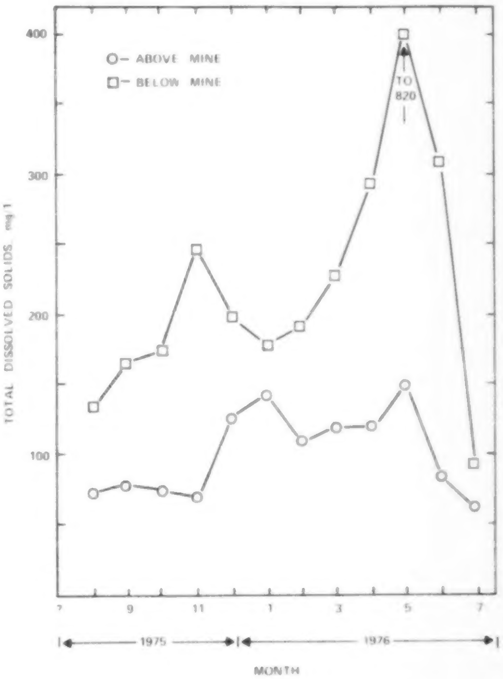

Figure 1. Monthly total dissolved solids (TDS) above and below the mine on Trout Creek.

Leaching studies have been carried out on mine overburden to: a. obtain information on the mechanistic aspects of the leaching process; b. provide data supportive of the general conclusions given above; and c. prepare leachates under controlled conditions for bioassay evaluations. Although such studies are subject to experimental problems as will be discussed below, they have provided bases for the following general conclusions.

1. The alkaline nature(s) of the overburden materials and associated ground waters definitely play major roles in controlling the solubilities of several potentially toxic trace metals.

2. The amount of organic material removed from the overburden by leaching is typically less than 5-10 mg organic carbon per liter. The compounds involved are primarily of the humic and fulvic acid types; these also limit the solubilities of several heavy metals.

3. Large quantities of water are required to leach the alkaline and saline constituents from the overburden. McWhorter et al. (2) have combined the knowledge of the leaching behavior with the hydrology and meteorology of the region to estimate that several centuries will be required to reduce the alkaline-saline contributions of a typical mine overburden deposit to a nonalkaline, nonsaline condition. Thus, these contributions to the aqueous systems due to the disruption of the strata overlying the coal will be long term.

4. Overburden leachates have been demonstrated to cause "mild" acute toxicities once the majority of the alkaline constituents have been removed via the leaching process. Although a particular constituent has not been identified as responsible for this, it appears most likely at present that the effect is due to the combined presence of several constituents at very low concentrations. The evaluation of this in terms of chronic effects is in progress.

Coal Combustion

To determine the impacts of coal combustion on the aquatic biota, the study area selected has been the power plant at Colstrip, Montana. The research has included chemical analyses of the coal being burned, the fly ash produced, the aqueous effluents, and the principal water course draining the plume impact region, i.e. Rosebud Creek. Fish and macroinvertebrate distributions in that stream have been determined and bioassays have been run on fly ash leachates as well as waters from the fly ash, scrubber water, and cooling water settling ponds. Based on the studies to date, the following generalizations can be drawn:

1. Fly ash leachates are acutely toxic to Daphnia even at high dilution levels. The results superficially suggest that the toxicity may be related primarily to the alkaline and saline parameters of the leachates. However, when the prevalent chemical equilibria are taken into account, the effects that these parameters have on the concentrations as well as the chemical forms of trace metals such as copper and zinc serve as the basis for this observation. This will be discussed further below.

2. Results to date indicate no correlative data between fish or invertebrate distributions and water chemistry changes in the plume impact area. Although this suggests that the aerial emissions are not significantly impacting the biota, the plant has been in operation for less than two years. Thus, possible longer term impacts cannot be evaluated yet.

3. Mercury concentrations in the plume impact stream rise rather sharply during periods of surface runoff such as the spring thaw. Computations indicate that the mercury emission level at the power plant stack should approximate 1 $\mu g/m^3$. Limited measurements have indicated that the atmospheric mercury concentration along the plume centerline in a 2 m/sec wind was 80 ng/m^3 at a distance of 1.8 km and was diluted to a level of 25 ng/m^3 along the same centerline at a distance of 2.4 km. Moreover, analyses of snow samples indicate mercury levels approximating 0.02-0.2 μg Hg per gm snow in the plume impact direction compared to levels one to two orders of magnitude lower for control samples. Thus, a plume scavenging-watershed flushing phenomenon is being investigated as the possible cause of the stream impact.

4. Chronic bioassays run on settling pond waters suggest low levels of toxicity to Fathead Minnows. Further tests are required, however, to validate this possibility.

Oil Shale Development

Field work associated with this phase of the program has concentrated on the characterization of the preoperational biological and chemical characteristics of Piceance Creek which drains the C-b Federal Lease Site. This data is being summarized for reference pending the development of oil shale mining and processing in the area.

Preliminary laboratory studies have also been carried out to characterize the leaching behaviors of retorted oil shales and to assess the possible toxicities of the leachates and fractions thereof. These efforts have shown that retorted shale leachates are acutely toxic to Daphnia under certain conditions. Further experimental work will be required to delineate the factors controlling the chemistry of the leaching process and define the constituents responsible for the toxicity.

Coal Conversion

The aqueous condensates derived from coal gasification and liquefaction processes constitute primary effluents. Analyses for the organics contained in the condensates obtained from three different gasification processes have indicated that major components are phenols and cresols with lesser amounts of several lower molecular weight carboxylic acids (3). The condensates from the three different processes show a fairly high degree of similarity in terms of the concentrations of the various compounds present. Although these samples have not been subjected to the types of pollution control procedures that would likely be associated with commercial scale operations, the studies carried out in the present program should prove useful in defining the possible toxicants and in formulating necessary control procedures.

It has been determined that the gasification condensates are toxic to Daphnia even when highly diluted. After separation of these waters into several fractions via a simple polarity separation procedure, the toxic entities are restricted to a few fractions. Verifications of the cause and effect relationships, quantification of the actual amounts and toxicities of the compounds present, and evaluations of the environmental behaviors of the compounds are in progress.

The above summaries are indicative of the status of progress of the present program and of the work yet to be completed. A comprehensive report on the evaluations of the coal mining impacts is scheduled for completion later this year. A similar report on the coal combustion phase of the program is planned for completion in early 1978. The experimental emphases of the program for FY '78 will be in the areas of coal conversion and oil shale processing. The presentation above has been general for the purpose of brevity. There are, however, experimental aspects of the program which deserve specific discussion as a means of emphasizing the complexities of certain problems.

Leaching Behavior

Leaching studies are being used extensively by numerous investigators for a variety of characterization purposes. In the summary above it has been pointed out that leachates of certain materials were found to be toxic under certain conditions. Such observations are due to the fact that several experimental factors can prominently affect the leaching process and the associated bioassay results. Leaching behavior depends primarily on three factors: a) the solubilities of the chemical species present in the material studied, b) the accessibility of the chemical species within the matrix to the solvent, and c) the solution equilibria which limit or enhance the solubilities of the species of interest. Consequently, when the leaching procedure maintains the material to be leached in contact with the leaching solution, all of these factors are operative in determining the final solution composition. This is illustrated in Figure 2 which presents example data obtained when fly ash from coal combustion was leached on a continuous recycle basis. Leaching in this manner resulted in a continual rise in the pH due to dissolution of alkaline materials. The hydroxide alkalinity developed reduced the soluble concentration of iron initially leached from the fly ash due to precipitation of iron hydroxide and simultaneously increased the amount of zinc dissolved via formation of soluble hydroxy complexes. Such discrepancies make it difficult to rationalize that the final bulk leachate is truly representative.

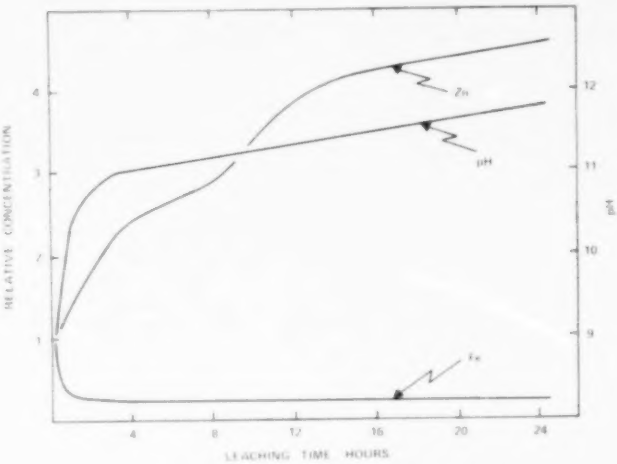

Figure 2. **The attainment of equilibrium in a continuous recycle leaching experiment.**

The prominence of the control of the solution equilibria also indicates that the solution volume used per unit mass of the material being leached is important. Table I summarizes evidence for this obtained by continuous recycle leaching of samples of the same fly ash using various volume-to-mass ratios. Again, the suppression of the solubilities of various elements when the pH of the leachate solutions and their alkalinities are high is readily apparent.

TABLE 1. DEPENDENCE OF ELEMENTAL EXTRACTION ON DILUTION (ML H_2O/G FLY ASH) FOR 24 HR CONTINUOUS RECYCLE LEACHING*

	Dilution, ml/g		
Element	100	1000	10,000
Ca	11,200	22,500	169,000
Cd	0.014	0.05	0.6
Cu	0.52	1.0	2.0
Cr	0.84	4.6	7.0
Fe	0.15	2.3	12.7
Mg	0.6	500	1900
Mn	0.05	1.3	7.0
Pb	0.15	1.0	7.5
Sr	380	620	2900
Zn	0.05	2.0	11.2
pH	11.5	8.5	8.2

*Values given are concentrations expressed as micrograms of element extracted per gm of fly ash.

The advantages of using a leaching approach in which the leachate solution is replaced by fresh water periodically to simulate environmental conditions more closely may be deduced from the example data given in Figure 3 where the solution was changed at each time interval plotted. The changes shown reflect the control of the solution equilibria on the solubilities within each time increment. The shifts seen following each solution change indicate removal of that control such that the effects of matrix composition and elemental accessibility to the solution can be inferred. Again, the suppression of solubilities during the early stages of leaching can be seen followed by enhancements in the removal rates later in the cycle due to decreased solution equilibria control. The dropoffs observed for zinc and cadmium in the later stages reflect the depletion of the soluble forms available in the fly ash. In essence, this approach permits the separation of the different effects which influence leaching behavior and the accumulation of information regarding the prevalent equilibria and the compound types and accessibilities. Such knowledge is essential to gaining a rational understanding of the leaching process, the development of the ability to reproducibly prepare leachates for bioassays, and the interpretation of the bioassay results.

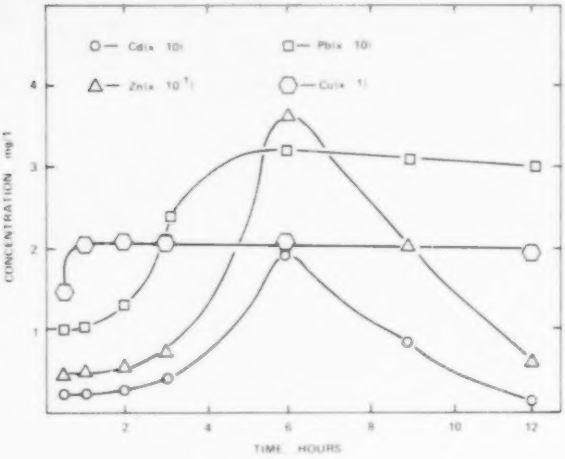

Figure 3. Attainment of equilibrium in a replacement recycle leaching experiment.

The necessity for understanding the leaching behavior and the importance of the chemical equilibria operative is further illustrated by consideration of bioassay results.

Interpretation of Bioassay Results

Numerous acute bioassays have been run, for example, on leachates of fly ash prepared by the method illustrated in Figure 3. The mortality results were correlated with the concentrations of the various chemical parameters to obtain first approximations of the entities that might play significant roles. The results summarized in Table 2 suggest that a dozen chemical parameters correlate with mortality. Examination of this list, taking concentrations into account, indicated, however, that most of the parameters judged to be significant were not likely to be directly responsible for the toxicity. Further evaluations also indicated that some other constituents leached from fly ash might also be important but other factors affected the ability to detect this based on the correlation analyses. This is illustrated in the example data of Figure 4 where the mortalities observed are shown to be correlated to the copper concentrations in the bioassay dilutions of several fly ash leachates from different periods of the leaching cycle.

TABLE 2. CORRELATIONS BETWEEN CHEMICAL PARAMETER CONCENTRATIONS AND DAPHNIA MORTALITY FOR FLY ASH LEACHATES

Chemical Parameters for which Correlation Coefficients Were:		
Significant at 0.01% level	Significant at 0.05% level	Not Significant
alkalinity	orthophosphate	dissolved solids
conductivity	lithium	chloride
pH	magnesium	cadmium
bicarbonate	nickel	chromium
carbonate		copper
barium		iron
calcium		potassium
strontium		manganese
		sodium
		lead
		zinc

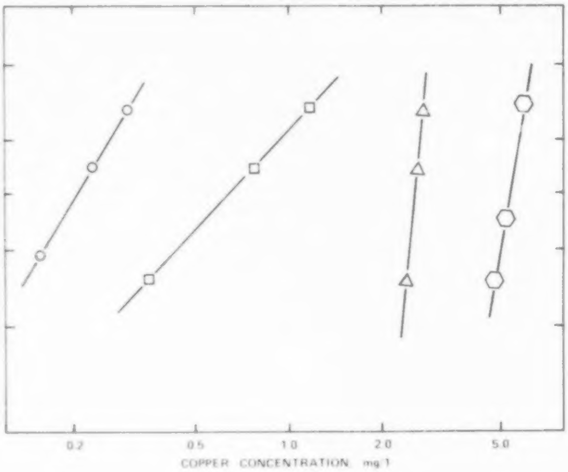

Figure 4. Apparent effects of copper on mortalities in different fly ash leachates.

These results distinctly imply that individual LC_{50} values can be defined for copper for each of these leachate fractions studied. The same is true for zinc and, possibly, lead nickel and chromium. The interpretations are complicated by the fact that, as the general leachate composition changes, the concentrations and chemical forms of several elements change simultaneously. The copper LC_{50} results also correlate nicely with the alkalinity levels in each fraction. It is possible that this is due to eqiulibrium control in which the amount of copper present as the dihydroxy complex ($Cu(OH)_2$) increases with increasing alkalinity. The amount of copper required to cause death increases accordingly due to this change in the primary form of dissolved copper. Similar postulates involving such equilibria apply to other elements. As a result, the assignment of cause and effect relationships in mixed constituent systems of this type must be carefully based on rather complete chemical analyses so that the chemical equilibria which may affect the toxicity question can be taken into account.

Coal Gasification Waters and Tars

A list of the compounds identified in the steam condensates for gasification has been published by Ho et al. (3). These include primarily phenols and cresols as well as carboxylic acids. Analyses of waters from three different processes in the present program agree very well with this report. Analyses of the water soluble constituents of tars derived from a single process indicate the presence of essentially the same compounds. Some example analysis results are summarized in Table 3. Bioassays run on these materials have demonstrated toxicity even when they are highly diluted. Column separations based on polarity have further shown that the toxicity is primarily associated with those fractions containing the phenols and cresols. Finally, it has been determined that the ultraviolet absorption at 270 nm which is a measure of the phenol plus cresol concentrations is linearly related to the degree of toxicity. Again, the importance of the chemical equilibria must be emphasized. These compounds are weak acids. As a result the pH of the recipient waters may well have an effect on the manifestation of the toxic effects. Moreover, these compounds can form chelates with metals present in the aqueous phase, thereby changing the functionality and/or the degree of toxicity for either the compounds or the metals involved.

TABLE 3. EXAMPLE ANALYSES OF COAL-GASIFICATION PRODUCTS

Sample Type	Sample Number	Concentrations, mg/l			
		phenol	o-cresol	M&P cresol	total
steam condensate	A	5.7	0.7	2.3	8.7
	B	4.1	0.5	1.7	6.3
	C	1.8	0.3	1.0	3.1
water soluble functions of tars	A	24.8	10.7	36.0	71.5
	B	20.0	11.8	38.6	70.4
	C	9.3	7.5	24.0	40.8

Conclusions

The majority of the conclusions have been outlined in previous sections. Although many of these must be regarded as tentative, the program is rapidly reaching a stage where they can be finalized. Perhaps, the conclusion that should receive most emphasis is simply that the careful coordination of the chemical and biological investigations is essential to: a) the delineation of the potential impacts on the aquatic biota, and b) the development of sufficient understanding of the systems investigated to permit prediction of long range impacts or the development of required control strategies.

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2. D. B. McWhorter et al., "Surface and Subsurface Water Quality Hydrology in Surface Mine Watersheds," Industrial Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

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EFFECTS OF CHEMICALS USED IN OFFSHORE WELL-DRILLING OPERATIONS

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INTRODUCTION

Recent environmental impact statements on oil and gas lease sales in the Gulf of Mexico have devoted proportionately little discussion to the environmental aspects of chemical use in well-drilling operations. This may reflect the fact that few studies have been done on effects and most tests utilize acute static bioassays which have little relevance to environmental conditions in which drilling and discharges occur. Of those acute bioassays published in the literature, few have reported severe adverse effects of drilling fluids or their components. In addition, observations of divers and fisherman reveal a variety of marine life in the vicinity of drilling rigs. Further, it is generally assumed that fluids would either have only a limited local effect near the plume discharge point or would rapidly be diluted and dispersed in the field.

Research on the effects of drilling muds is further impeded by the chemical complexity of muds. Additives contain: pH control products, bactericides, calcium removers, corrosion inhibitors, defoamers, emulsifiers, filtrate reducers, flocculants, foaming agents, lost circulation materials, lubricants, shale-control inhibitors, surface-active agents, thinners, dispersants, viscosifiers, and weighting agents. Analyses of potential effects of chemicals used in well-drilling operations must take into account the variation in mud and cutting composition due to the type of substrate drilled, well depth, availability of mud components, temperatures generated, relative cost of components, operator experience, etc.

The "King-Muir" report included the following gas and oil environmental effects objective and project as a national need:

"Objective A: Determine the fate and effects in marine and estuarine ecosystems of pollutants of oil and gas extraction activities...

...Project 2: Determine the ecological effects on marine and estuarine organisms of pollutants from oil and gas extraction."

A rigorous biological assessment of potential environment effects of chemicals used in well-drilling operations has many technical difficulties and is extremely resource intensive. Because of these considerations, a limited program to study the effects of drilling mud components was undertaken at the EPA Environmental Research Laboratory at Gulf Breeze. There are many areas in which a thorough understanding of the effects of drilling muds in the Gulf of Mexico is lacking:

(1) estimates of the distance that active rigs should be located from coral reefs and other biological resources to minimize potential effects from emissions,
(2) effects of mud on resident rig marine life;
(3) advisability of aquaculture on or near platforms;
(4) recommended distance from rigs for seafood harvesting;
(5) advantages and disadvantages of shunting drilling muds.

A better understanding of the effects of drilling fluids will provide a more substantial basis for policy regarding mud discharges and the content of lease stipulations.

TECHNICAL DISCUSSION

Our approach to an assessment of the effects of chemicals used in well-drilling operations is represented by the pyramid-shaped diagram shown in Figure 1. The experimental design follows a tiered screening sequence beginning at the base of the pyramid. Progressively more complex and time-consuming tests are run on fewer compounds as the testing sequence progresses upward. Xenobiotics are selected from lists of drilling mud components in current environmental impact statements, with emphasis on those characterized by heavy usage patterns or having suspect toxicity.

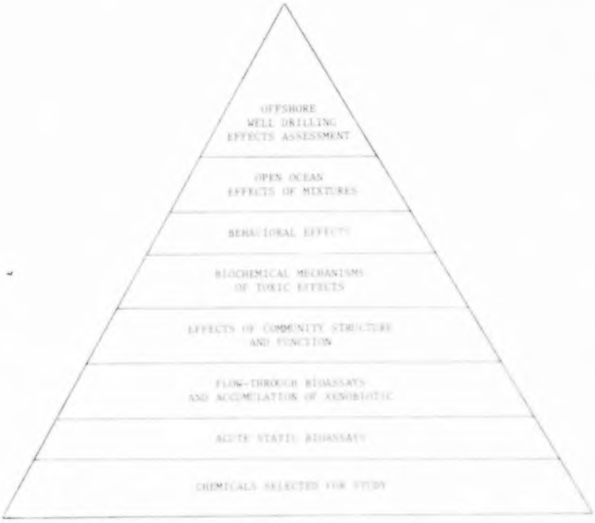

Figure 1. Effects Assessment of chemicals used in well-drilling.

Preliminary screening of selected compounds--the second ascending tier of the pyramid-- is accomplished by acute 96-hour bioassays. They are conducted with drilling fluid constituents by using laboratory-reared sheepshead minnows (*Cyprinodon variegatus*) and grass shrimp (*Palaemonetes pugio*). These range-finding tests are helpful in selecting toxicant concentrations for subsequent flowing seawater bioassays for each compound, component, or mixture of interest. This is represented by the next ascending progression in the pyramid.

Flow-through toxicity methods were selected for a second tier of testing because they more nearly approximate *in situ* conditions. In contrast to static tests, metabolic products and excreta are removed while oxygenated seawater and toxicants are continuously supplied. Data obtained from flow-through toxicity tests are generally preferable over static tests as the more precise measure of toxicity and bioaccumulation. A few compounds are selected from flow-through experiments for the next tier of testing: the composition and functions of estuarine communities.

The effect of selected xenobiotics on colonization of planktonic larvae and microorganisms is analyzed by means of the apparatus developed at the Gulf Breeze Laboratory. The apparatus used in these studies uses unfiltered seawater with its natural component of plankton and microorganisms pumped from the estuary adjacent to the laboratory into the primary constant head box. Xenobiotics are continuously metered into water after they are siphoned from the primary to the secondary constant head box. The control apparatus receives the same flow of water. Water then flows from the secondary constant head box to each of the 10 adjacent aquaria -- 10 replicates for each treatment, including controls. At the end of a nine-week exposure period microflora, macrofauna, and meiofauna are sampled. To determine the effect of the xenobiotic after each treatment, numbers and species of microflora, meifauna, and macrofauna are compared in control and exposed aquaria. Concentrations of xenobiotics in test water and sediments are determined. Samples of water from the constant head boxes are taken twice a week and sediment cores from aquaria are taken from each apparatus at the end of the exposure.

RESULTS

Two compounds were selected for further study from those screened in acute bioassays. Barium sulfate was chosen because "...barite discharged with drilling muds is a *nontoxic* substance." Pentachlorophenol was chosen because it is a "...potentially hazardous" drilling mud constituent, according to a recent EIS.

Static toxicity tests with sodium pentachlorophenate have been conducted with larval stages of three marine/estuarine species. The species, the LC_{50} values obtained, and the respective exposure period were: eastern oyster, <100μg/ℓ, 48-hr; grass shrimp, 649μg/ℓ, 96-hr; and pinfish, 38μg/ℓ, 96-hr. A similar study with Dowicide G (79% PCP) and pinfish larvae resulted in a 96-hour LC_{50} of 66μg/ℓ. A bioconcentration study with oysters exposed to sodium pentachlorophenate in flowing seawater for 28 days demonstrated the bioconcentration of 80 times that measured in the exposure water. Similar exposure experiments have been done with barium sulfate. Grass shrimp (*Palaemonetes pugio*) were observed ingesting barite.

Effects of pentachlorophenol on development of estuarine settling communities were determined by using the apparatus devised by Hansen and described under the technical discussion section. The analyses of macrofauna from a 9-week exposure revealed that individuals and species of the numerically dominant phyla (Annelida, Arthropoda and Mollusca) decreased as concentration increased. Sensitivity differed among species of the same phylum. For example, the population of the annelid *Haploscoloplos* was reduced by exposure to 96μg/ℓ PCP, but not *Capitella capitata*. Molluscs markedly decreased at 7μg/ℓ; annelids and arthropods at 76μg/ℓ. Few macrofauna occurred at 622μg/ℓ. Total number of animals and species were significantly less ($\alpha = 0.01$) in aquaria exposed to 76μg/ℓ than in those unexposed or exposed to 7μg/ℓ. Therefore, pentachlorophenol altered the structure of experimental macrofauna communities that developed during exposure by changing the relative abundance of animals by species and phylum.

Meiofauna community structures were harvested from the same tanks as the macrofauna. Although there were structural changes in the community, this is not shown by any of the species diversity indices used. However, there was a shift in nematode feeding types as a function of pentachlorophenol concentration. An analysis of the species revealed that the meiofauna population shifted to predominately detritis feeders in 622μg/ℓ of pentachlorophenol. Therefore, the shift of meiofauna functional types is correlated with PCP concentration. This experiment indicates that utilizing metazoans as an effects indicator in the test system described may have distinct advantages. They have relatively short life cycles, adults normally will reproduce prolifically, and they invade the system rapidly. Therefore, structure and functions of meiofaunal communities can be determined. The number of cultivatable microorganisms was significantly lowered in aquaria with high pentachlorophenol concentrations.

PROGRAM DISCUSSION AND CONCLUSIONS

Literature on the effects of chemical use in offshore well-drilling operations on marine organisms is very limited. Policy decisions are currently based on static, 96-hour LC_{50} determinations, observations of divers, and theoretical models of pollutant dispersion. A limited research program on drilling-fluid constituants has been initiated at the Gulf Breeze Laboratory to provide a better data base as one component in the prediction of the relative hazard of using alternative drilling mud constituents and to develop more relevant laboratory methods for xenobiotic evaluation. Pentachlorophenol and barium sulfate were used as reference compounds to evaluate the applicability of our methods for determining effects of whole drilling muds in our assessment program. It is obvious that the methods ultimately used for an assessment of the effects of chemicals used in offshore drilling operations should use a variety of muds from different depths and locations. Testing protocols should include effects on the structure and function of communities, indirect effects of pollutants, bioaccumulation potential, toxicity of mixtures to organisms indigenous to lease areas, attraction of marine species to chemicals used in well-drilling operations, and mechanism of action in toxicants. In this way, choices between the multitude of alternative chemicals available for well-drilling operations can be based on better toxicological information. Hard data on effects might also eliminate unjustified concern about the effects of certain chemicals, which may in fact be safely used in well-drilling operations.

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TABLE 1.

LIST OF STUDY ELEMENTS, PRINCIPAL INVESTIGATORS, AND GRANTEES DURING THE FIRST YEAR OF RESEARCH ON CHEMICAL USE IN OFFSHORE WELL-DRILLING ACTIVITIES

INVESTIGATION OF EFFECTS AND FATES OF POLLUTANTS

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INTRODUCTION

Most of our information on the effects of pollutants in marine systems comes from experiments to determine concentrations which are lethal or physiologically and behaviorally effective for various species maintained in laboratory aquaria, or from observations of unhealthy conditions in grossly polluted areas. Most of our information on the fate of pollutants in marine systems comes from observations in natural systems.

One difficulty with observations of the type described is that for the purpose of examining biological effects it is never possible to examine more than a small fraction of the numerous species present in any natural ecosystem, and there is always the suspicion that critical but sensitive species may be missed, or that sensitive life stages of species which are examined may be missed. It is also possible that organisms maintained in laboratory aquaria may be subject to sufficient stress that they become more sensitive to various pollutants. In any case, experiments with isolated species may require supplemental information in order to provide convincing results. As for observations of the fates of various pollutants, there is a dearth of controlled experiments. Most observations of the inadvertent introduction of various pollutants into natural systems suffer because of frequent multiple pollutant effects, lack of replication, lack of the possibility of budgetary control of amounts of materials involved, or lack of control over the various environmental parameters that may be of importance. In many cases, therefore, we are not able to make quantitative predictions about the pathways followed by a substance introduced into the marine environment, nor about its ultimate fate.

Accordingly, it seemed highly desirable to make the attempt to set up microcosms of the marine environment in which experiments could be carried out in replicate, under controlled conditions, and in which both the effects and fates of various pollutants could be investigated. Previous and current experience with such approaches (Abbott 1966; Davies et al. 1975; Odum et al. 1963; Smetacek et al. 1976; Takahashi et al. 1975)suggested that marine microcosms would replicate poorly and be difficult to maintain for any length of time, and would be costly and involve considerable technical or engineering difficulty. Nevertheless, the potential value of the approach encouraged us to continue.

The marine environment of the northeast coast of the United States, both estuarine and on the continental shelf, may be characterized broadly as consisting of communities in which most of the photosynthetic activity is carried out in the water column by phytoplankton, and in which there is a significant chemical and biological coupling with the bottom. The benthic animals filter out some phytoplankton, and there is a rain of organic debris which is metabolized on the bottom. The benthic return of nutrients may be a significant factor in the overall cycling.

Accordingly, the microcosms set up at MERL are designed to be coupled planktonic-benthic systems. Our first task was to evaluate the biological and chemical behaviour and replicability of these systems, and their utility in studies which seek to provide quantitative information on the effects and fates of low concentrations of pollutants.

DESCRIPTION OF FACILITY

Tanks

Twelve fiberglass tanks (Fig. 1) are set up outdoors on concrete pads ranged alongside a "dock" structure which provides access to each tank. The tanks are 5.5 m high and 1.8 m in diameter. The walls are smooth and white, and backed by insulation to prevent excessive heat transfer through the walls. Each tank has several fittings for adding or draining water. Glass heat exchangers (not shown) allow heating or cooling each tank sufficiently to maintain their temperature up to 10^{o} different from ambient.

Water

Each tank contains about 13 m^3 (13 tons) of water from Narragansett Bay. The water is supplied, from about 30 m offshore along the GSO dock, by a diaphragm pump that appears to be non-destructive to at least the smaller forms of plankton. The water is delivered through fiberglass and PVC pipes to a fiberglass header tank, from which it flows by gravity to each of the 12 microcosms. Each microcosm tank has a flow control regulating the water input. The tanks have been run so far in two modes: batch (no flow-through), or slow-flow with an input rate of 300 ml per minute (432 liters per day) resulting in a turnover time of water in the tanks of about 30 days.

Sediments

A sediment container in the bottom of each tank contains sediment collected from a selected area N.W. of Conanicut Island, Narragansett Bay. This region has a depth of about 8 m, and the bottom is a fine silty mud supporting a community characterized by the presence of Nucula and

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Nephythys. The sediments were collected by grab and placed in the containers (on board a boat) using as much care as possible to keep the material in its original orientation, although considerable mixing took place. The containers were then returned to land, placed in the tanks, and water run in to cover them. Each container has about one ton of sediment, which fills it to a depth of about 30 cm. The biological community living in the sediments in the tanks has remained similar to that in the source area.

Mixing

It was thought essential to provide some turbulence in the tanks. A considerable tidal stirring of Narragansett Bay occurs, a process which resuspends lighter materials from the bottom. The stirring regime in the tanks was designed to provide an input of turbulent energy across the bottom sufficient to achieve resuspension of lighter particles. This is accomplished by the plunger shown in Figure 1, which moves up and down, directing the major turbulent energy to the bottom. The introduced turbulence also provides a general mixing of the water column in the tanks. The mixer has normally been run on a cycle of 2 hours on and 4 hours off or ½ hour on and 1½ hours off. All tanks are mixed synchronously.

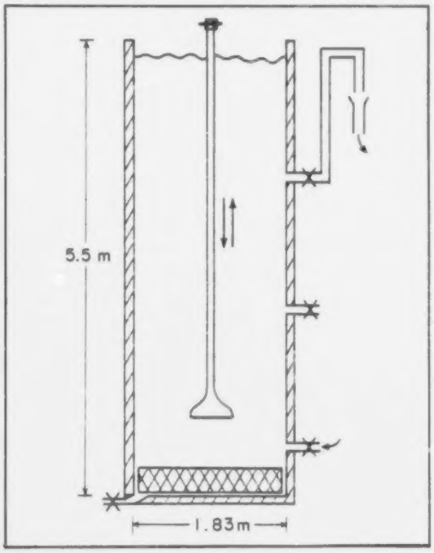

Figure 1.

Diagram of one of the MERL tanks. Each fiberglass tank is insulated and has three flanged ports on the side and one drainage port. The sediment container, also of fiberglass, contains about 30 cm of sediment. The tanks are filled through a port on the side and during slow flow operation, water exits from about 1 m below the surface through a level control stand pipe. The depth of water is about 5m. The mixer moves vertically through an excursion of about 60 cm with a frequency which is variable but is now set at about 5 cycles per minute.

Cleaning

A stainless steel ring bearing a series of brushes is lowered and raised in each tank at necessary intervals to remove growth from the walls. This is carried out twice weekly in the summer and less frequently in the winter, and has been effective in preventing growths of attached plants and animals. Occasional supplementary hand cleaning has also been necessary.

Initial Operations

Nine of the MERL microcosms were loaded with sediment, filled with water, and set in operation during August of 1976. During the first four months of operation all tanks were run in as similar a way as possible, although some variations occurred as operations were modified and experience was gained. In December an experiment on the addition of oil was carried out. A water-accommodated fraction of No. 2 fuel oil was prepared by shaking the oil with water from the tanks and allowing the resulting suspension to stabilize for one-half hour. The aqueous phase, containing oil in solution and as small droplets in suspension was added to three tanks by teflon delivery tube about one meter below the surface during mixing, so that it was well distributed within the tanks. After addition, the concentration was about 150 μg per liter. The temperature of the water at that time was about 5°C. The concentration of hydrocarbon was monitored until it dropped to background levels (about 3 μg per liter). In late December an unusually cold period occurred and some of the seawater delivery lines froze. From 28 Dec. until 14 Feb. all tanks were operated in batch mode; i.e. no seawater flowed through. In the middle of February six tanks were returned to flow-through operation and three kept with no flow-through in order to examine the effect of the two types of operation. Additional oil experiments are also being carried out.

INITIAL OBSERVATIONS AND RESULTS

Biological

Regular monthly counts have been made on the benthic animals, and weekly counts of zooplankton and phytoplankton. Weekly measurements of nutrient concentrations, phytoplankton productivity, and a number of other observations have also been made. Much of this information is still being prepared. Here we present only the averaged data for the concentration of chlorophyll a, a measure of the standing stock of phytoplankton. Figure 2a shows the mean concentration of chl a in the nine tanks, along with the highest and lowest concentrations observed each week. Figure 2b shows the concentrations of chl a in weekly samples of water from the GSO dock, near the intake for the seawater supply system.

A striking feature of these graphs is the similar timing of the various blooms and decreases in phytoplankton abundance in the tanks and in the

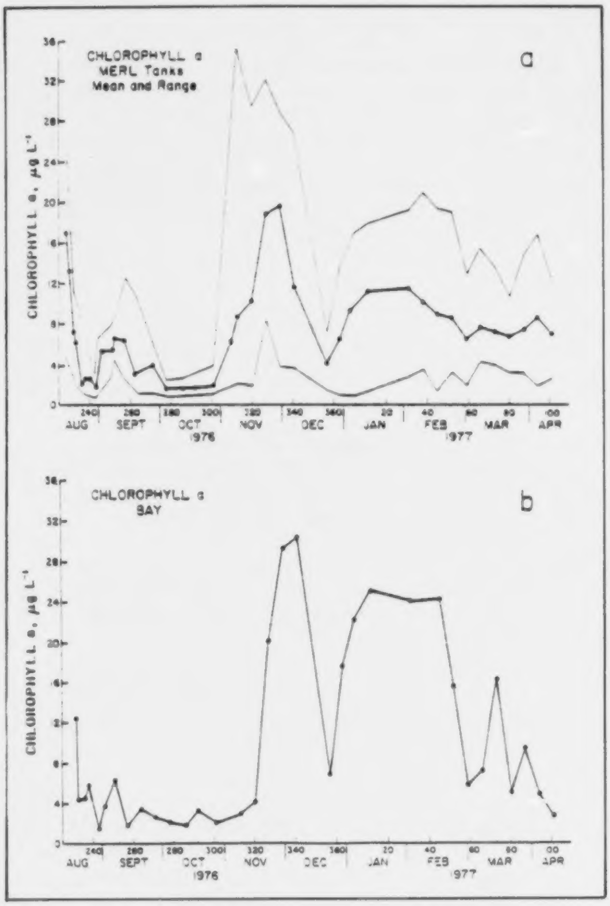

Figure 2 (a). Mean and range of weekly measurements of the concentration of chlorophyll a in nine MERL tanks (b) concentration of chlorophyll a in water from the GSO dock near the intake for the MERL system. After 15 Feb. only eight tanks were included in the average, as additional treatments were applied to one of the tanks.

bay. The tanks were filled towards the end of a bloom in the bay, and the decrease in the bay had its counterpart in the tanks. Each tank followed a similar course; however, the timing of the chlorophyll maxima or minima differed between tanks by one to three weeks. Generally the major features found in the bay were found in the tanks. From late December until the middle of February there was no flow through the tanks, and for two or three weeks in January there was an ice cover on the tanks. Nevertheless a bloom occurred in the tanks as it did in the bay, although here the average concentrations of chl a were distinctly lower. This indicates that even though there has been considerable variability from tank to tank, the overall behavior has been remarkably similar to that in Narragansett Bay. The phytoplankton species composition has varied from tank to tank and from time to time, but all species which have been dominant during blooms are normally found in Narragansett Bay.

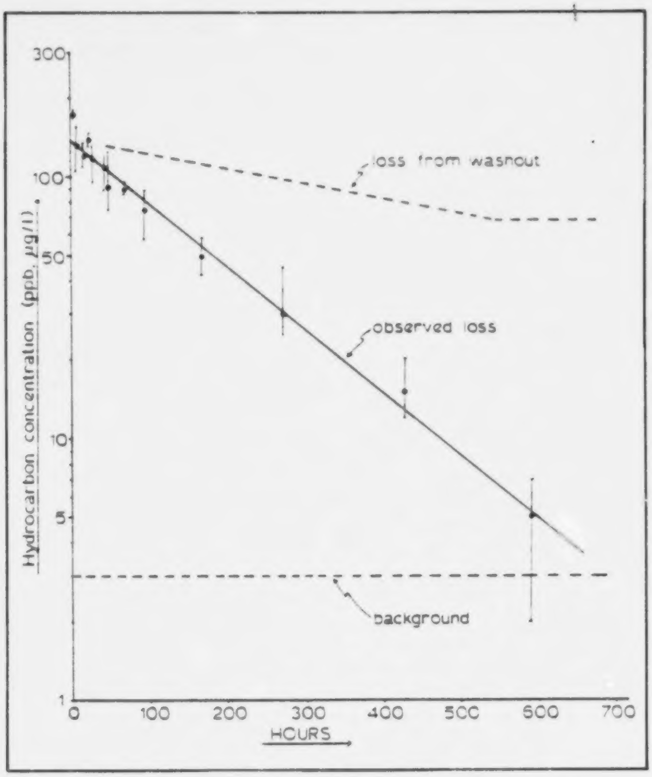

Figure 3. Change of hydrocarbon concentration with time after addition of a water accommodated fraction of No. 2 fuel oil to MERL tanks. Mean and range of measurements in three tanks. Tanks operated on slow flow-through mode; half-life of water in the tanks about 500 hours. Half-life of oil about 120 hours.

Oil

In the first oil experiment (Figure 3) the loss of oil was exponential; the half-life of the oil was about five days. The initial concentrations had little effect on numbers of phytoplankton or on productivity. There may have been some temporary effect of the oil on the zooplankton, but the oil did not remain long enough to find out for sure. At the present time we don't know where the oil went. Not more than 5% of the added oil reached the surface sediments, and none could be detected after one month. Some may have been metabolized, and some lost as vapor to the atmosphere. Further experiments are now underway to evaluate the various paths by which oil may be lost from the water.

DISCUSSION

Having run the MERL microcosms during late summer, fall, the most adverse winter weather and into the spring we feel relatively confident that they can be run for a year or more, or perhaps indefinitely. The chief limitation at the present time is the amount of sediment in the tanks. This is depleted slowly by the taking of samples for analysis, and eventually will have to be replaced.

The causes of blooms, species succession and declines in abundance of phytoplankton in Narragansett Bay are only partially understood. Factors thought to be important are nutrient limitation, nutrient regeneration, and grazing (Smayda 1973; Vargo 1976). The similar behavior between the tanks and the bay, in bloom dynamics and species succession, suggests that similar control mechanisms were operative. It was surprising to find the overall behavior showing such a parallel with Narragansett Bay, and it will be interesting to observe the future behavior in this regard. In order to establish that the MERL microcosms are a sufficiently realistic approximation to nature that the results will be meaningful it would probably be sufficient for the tanks to show approximately the same statistical behavior, similarities in bloom dynamics and to have most of the important species the same. It appears that the MERL tanks may be a useful experimental setting within which to investigate the causes of phytoplankton blooms, succession and decreases.

The results of the first oil experiment were also surprising. The conventional wisdom would have it that oil in the water column would enter the sediments where it would remain. Some resuspension of sediments occurs in the tanks, which should help to remove the oil. However, oil was not found in the sediments to any significant degree, and it has either been metabolized or escaped to the atmosphere. Currently we are evaluating the rates of both these processes. Since the amount of oil put in the tanks is known, and also the amount washed out, it should be possible eventually to provide quantitative estimates of the magnitudes of the various pathways by which hydrocarbons are lost from the systems.

Detailed descriptions of the physical, chemical and biological behavior of the systems are in progress and will shed additional light on the functioning of the microcosms and on their utility in ecological experimentation.

CONCLUSIONS

1) While the experience gained to date is confined to only a portion of one year, it does seem likely that it will be possible to run coupled planktonic-benthic microcosms of the type established at MERL through at least one annual cycle, with a chemical and biological behavior that approximates to the behavior of analogous natural systems.

2) These microcosms should be useful tools with which to provide quantitative information on the effects of various organic, inorganic, or radioactive pollutants on the lower trophic levels of marine ecosystems. It should also be possible to provide quantitative estimates of the pathways followed, operative equilibria between sediments, water and organisms, and the fates of pollutants and other substances that may be added.

ACKNOWLEDGEMENTS

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EFFECTS OF COAL-FIRED POWER PLANT EMISSIONS ON TERRESTRIAL ECOSYSTEMS

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INTRODUCTION

In recent decades, human activities have greatly increased total emissions of substances to the atmosphere and their subsequent deposition from the atmosphere mainly through increases in combustion of fossil fuels; use of fertilizers and other chemicals in intensive agriculture and other forms of land management; and disposal of industrial, urban, and agricultural wastes. Atmospheric pollutants are imported, transported, exported, accumulated, and often changed before they are deposited. The effects of deposition of pollutants may be beneficial, detrimental, or both. They may be immediate, acute, and apparent, or they may be delayed, chronic or accumulative, and subtle.

State and Federal agencies concerned with the environment need information that will give them a basis for effective action for dealing with environmental crises when they occur and, more importantly, to prevent the occurrence of such crises, which frequently are quite costly, both economically and ecologically. Both general and specific information about the state, structure, and function of the terrestrial environment is essential for determining the extent of the changes that are induced by man's activities and that can be controlled.

Efforts to prevent or solve environmental problems are more likely to succeed if they are based upon a thorough knowledge of the processes that occur in the ecosystem and if this knowledge can be integrated with other factors that affect the environment, including economic, technological, and sociological considerations. The research needed to provide this required knowledge of the ecological effects and impacts of atmospheric emissions should be approached on three levels--the species, the community, and the ecosystem--and then the results of studies on these levels should be synthesized into an integrated approach. Study at each level increases understanding of environmental response on that level and, when integrated with the results from investigations on the next level of complexity, adds to our understanding of response at the more complex level as well.

Studies at the species level may include work at the tissue, cellular, or subcellular levels, but they generally deal with one or two species, are conducted under highly controlled conditions in which only the condition being studied is varied, and measure instantaneous or short-term responses by individual specimens. Studies on this level generally provide insight into the physiological response of individuals and aid in the determination of the actual response mechanism.

Although research conducted at the species level provides excellent opportunities for studying the mechanisms of response, it cannot be assumed that the kind or extent of the response observed would be the same under less controlled conditions. Studies of a community, an aggregation of living organisms with relationships among themselves and with their environment, tend to approximate actual environmental responses more closely than do studies of individual plants. Many of the responses studied at the species level can also be studied at the community level, and greater generalization is possible because these responses can be evaluated in terms of the collective response of the community. However, much less control of experimental variables is possible in studies on the community level because of (1) the increased importance of interacting factors, (2) competition among individuals and species, and (3) in many cases, the introduction of a greater number of variables in the naturally occurring physical environment. Community-level studies generally require more time than species-level studies. They may deal with mixed stands or monocultures with relatively small aggregates of organisms (such as field plots or microcosms) or rather extensive aggregates (such as forest stands or agricultural crops).

Most environmental problems are evaluated on the ecosystem level. By strict definition, a community usually constitutes an ecosystem because it includes living organisms and nonliving substances interacting to produce an exchange of materials. A more widely accepted concept, however, is that an ecosystem consists of a group of communities, which together provide a much greater variety of biological expression and physical features than any one community. The concept of the ecosystem is somewhat artificial because it separates a continuum into distinct units for the convenience of man's understanding. Nevertheless, response at the ecosystem level is probably the least understood of all levels and the one in greatest need of quantification. The response observed at the ecosystem level is an integrated one because of the differences in response within and between species and communities and because of the interaction of system processes, mechanisms, and transfers. The increased complexity and associated variability of work under essentially uncontrolled conditions require several years of constant observation and comparative studies at several locations for a realistic evaluation of the many facets of system response.

It is at the final level of complexity, the synthesis level, that information obtained on the other three levels is combined with information on the physical and sociological environment so that a predictive and evaluative capability can be developed for the total environment.

DISCUSSION

Species Level

Key Factors in Studies of Individual Effects. Studies at the species (whole-organism) level are conducted under precisely controlled conditions to isolate and characterize the effects of interacting variables. Effects on plant productivity, physiological and morphological effects, changes in a plant's susceptibility to insects and disease, genetic effects, and nutrient content are most frequently studied. The complexity and sophistication of experiments increase as knowledge is accrued until a model that encompasses all components of a system can be constructed to explain a particular relationship of cause and effect.

Effects on productivity, which may be qualitative or quantitative, may include vegetative or reproductive components or such components as fats and oils. Physiological and morphological effects include effects on photosynthesis, respiration, enzymatic and hormonal action, fruit set, abscission of plant parts, or alteration of growth and development characteristics. Changes in a plant's susceptibility to insects and disease involve qualitative and quantitative and direct and indirect effects of the potential of plants for resistance or susceptibility. The study of genetic effects includes somatic manifestations induced in affected plants and changes transmitted to subsequent generations through effects on reproductive systems. Effects on reproductive systems may be important in studies of pollutants with mutagenic potential. The effects on the nutrient content of plants exposed to pollutants include changes in the food quality of edible plants or plant parts, accumulation of toxic chemicals, and biochemical accumulation in the food chain.

Although the foregoing discussion does not necessarily represent all factors that should be considered in studies of the effects of a pollutant on a species, it includes the most important ones for a complete research program.

Research in Progress. Present efforts at the species level include controlled exposure studies of the effects of power plant emissions on cultivated and forest crop species of economic importance in the southeastern United States. The chief objective of the project is to determine the impact of simulated ground-level concentrations of sulfur dioxide (SO_2) and nitrogen dioxide on the productivity of plants. The differential sensitivity of plant species and cultivars will also be characterized by using this type of exposure system.

In previous research on the effects of SO_2 on plants, the plants have been exposed to a constant, average concentration over the entire time; unfortunately, such exposures do not reflect the rapid changes in concentrations of pollutants that are encountered in the field near coal-fired power plants. Response of a plant to a steady exposure may differ significantly from response to exposures of fluctuating concentrations.

For this project, a system capable of reproducing under controlled conditions the fluctuating concentrations of pollutants typical of field exposures was developed and tested. The system operates on the principle of feedback control by comparing the SO_2 concentration of the program with the actual concentration within the chamber to determine the volume of SO_2 to be injected into the chamber. Input and output signals are processed by a controller that continuously compares the two signals and activates flow valves that meter the SO_2 into the chamber. Air is sampled continuously from that chamber and analyzed to produce an output signal. A capacitive probe on the programmer follows the program line drawn on the conductive surface of a revolving chart.

An exposure cabinet large enough to accommodate plants of moderate height and maturity was designed, constructed, and tested. Air is circulated within the cabinet by two air blowers; one forces air into the cabinet, and one pulls air from the cabinet. A slight positive pressure is maintained. The cabinet consists of two compartments, one for exposure of plants and one for control.

Community Level

Key Factors in Studies of Community Effects. Studies at the community level are conducted under field conditions to duplicate communal relationships among plant species. The degree to which this level is manipulated depends on the species under study: intense manipulation as in an agroecosystem, moderate manipulation as in a managed forest, or no manipulation (a completely undisturbed system) as in an unmanaged forest. Some factors studied at the species level can also be studied at the community level although the same level of control of interacting variables and environmental factors that influence plant growth and development is not possible at the community level. However, certain factors that cannot be measured at the species level can be measured at the community level. These include nutrient cycling from one trophic level to another, species composition, population dynamics, and insect and disease interactions among plant species. Nutrient cycling includes leachates from aerial organs, root excretions, decomposition by various trophic levels, and nitrogen fixation. Species composition includes succession and competition for nutrients and light. Population dynamics include interactions with site factors and competition among plant species, including competition for the same site. Insect and disease interactions include changes in susceptibility, species preference, and transmission of infectious agents among host plants by insects.

Research in Progress. Work in progress at the community level includes development and use of a new field system for studying the effects of emissions from coal-fired power plants on food and fiber crops of economic importance in the southeastern United States. The system, called an air-exclusion system, consists of a large air blower that blows purified air below the canopy of plants grown in 0.004-hectare (0.01-acre) plots. The blower is activated by an SO_2 monitor and operates only when the SO_2 concentration exceeds 262 $\mu g/m^3$ (0.1 ppm). Thirty air-exclusion units were installed at five sites in 1976. Crops studied to date include soybeans, cotton, winter wheat, white pine, and Virginia pine. The air-exclusion system is used in lieu of field chambers. The principal advantages of the air-exclusion system over field chambers are that (1) air does not need to be circulated continuously because no enclosures are used and (2) the system operates only under exposure conditions so that plants are undisturbed except during exposures.

Research is in progress to measure the amount of sulfur that is transferred from the atmosphere to agro-ecosystems and to evaluate the economic significance of atmospheric sulfur on crop production. Deposition of atmospheric sulfur may be beneficial to crop production in areas in which the soil supply of sulfur is not sufficient to maintain optimum yields.

The concentration of sulfur varies in soils that have different organic matter contents and that have experienced different management practices. Supplemental sulfur must be added if the soil supply is too low to maintain optimum yields. For atmospheric sulfur to have economic significance on crop production, a need for supplemental sulfur must exist and the amount of sulfur that is transferred from the atmosphere must make up a relatively large proportion of the supplemental needs. Sulfur supply in representative soils of the Tennessee Valley is being evaluated and will be compared with the sulfur requirements of various crops to establish supplemental sulfur needs.

The transfer of sulfur from the atmosphere to plants and soils by deposition of dry particulates and rainfall can be measured directly. Development of a technique for measuring the sorption of gaseous SO_2 by plants and soil under field conditions is another part of this investigation. One promising method is to label the sulfur in the soil with radioactive sulfur and measure the dilution in specific activity within the plant that results from accumulation of sulfur from the atmosphere.

Another study underway at the community level involves a microcosm approach to the evaluation of the effects of acid precipitation on plants and soils. Specially constructed microcosms are exposed to the ambient environment except during periods of naturally occurring precipitation. Artificial precipitation, adjusted to four pH treatments, is applied to the microcosms. Comparison of plant and soil response to each treatment will provide insights into the short- and long-term effects of acid precipitation.

Ecosystem Level

Key Factors in Studies of Ecosystem Effects.

The definition of an ecosystem given earlier emphasizes the inseparable nature of organisms and their environment, which together form a physical system. This concept of the ecosystem is somewhat artificial in that it tends to segregate overlapping and interacting systems into isolated units for convenient study. The definition places little restriction on the area or spatial volume to be included in delineating an ecosystem; nevertheless, carrying this definition to extremes in either direction entails the risk of overgeneralization or disconnected finiteness. The problem, then, is to choose a realistic experimental unit whose integrated systematic response has practical importance in solving ecological problems.

A watershed defines a practical ecosystem that (1) reacts to inputs from the atmosphere, (2) depends largely on the regolith for nutrition, and (3) is subject to irreversible losses, but resists such losses by constant recycling and biosynthesis. Effects of perturbations in the ecosystem can be observed by monitoring the system (watershed) outputs (water, nutrients, and energy) in much the same manner as community responses are evaluated. The ecosystem response can only be measured as an integration of the different responses within and among various species and communities and of the interactions of system processes, mechanisms, and transfers. The increased complexity and associated variability of work under uncontrolled conditions require several years of constant observation, and comparative studies at several locations for a realistic evaluation of the many facets of system response.

Research in Progress

Little has been done to characterize the fate of air pollutants, such as sulfur and nitrogen oxides, in forest ecosystems. Small experimental watersheds provide a means for studying the effects of atmospheric pollutants on internal nutrient cycles and water quality. Camp Branch and Cross Creek experimental watersheds, located 95 and 19 km, respectively, from the Widows Creek Steam Plant, are being established to provide comparative data (not yet available) on (1) the elemental composition of wet and dry atmospheric input, (2) the ability of forest canopies to scavenge airborne pollutants and the fate of these pollutants once scavenged, (3) the influence of air pollutants on the general fertility of the soil and the ability of the soil to act as a long-term sink for air pollutants, and (4) the determination of allowable changes in system processes and transfers as a function of air quality. The soils and vegetation complex on the Cumberland Plateau are ideally suited to this type of study because any positive or negative impact should be easier to detect because of the relatively infertile and unbuffered nature of the soil.

During the past year, much of the time was spent selecting study sites and developing physical facilities. During the construction phase, certain parts of the program not dependent on the full development of the physical facilities were initiated: (1) Vegetation and soil surveys were completed at Camp Branch, and soil samples were collected for chemical analysis; (2) intensive study plots were established and described quantitatively; (3) litter traps and throughfall collectors were installed; (4) routine collections of litterfall were begun; (5) a study of litter decomposition was begun; and (6) 60 whole trees were harvested to aid in the development stand biomass estimates at both sites.

Construction and development of physical facilities and instrumentation are continuing, and operation is expected to begin in early May at Cross Creek and early November at Camp Branch.

Synthesis Level

The synthesis level carries environmental research to a fourth and final level of complexity, which integrates ecological considerations with economic and sociological data to evaluate the total environmental complex. To provide relevant information on the complexities of ecosystems and the observed or anticipated responses of ecosystems to environmental perturbations, a balanced approach must be taken to the research hierarchy discussed previously. Because most energy enters ecosystems and is fixed by photosynthetic plants, any perturbation that alters this response either directly or indirectly will affect all other organisms in the system. Although understanding plant response to perturbation on the level of the species or individual plant is important, the magnitude or even the response should not be assumed to be the same under the more varied conditions of the natural environment. Consequently, information obtained at the species level must be evaluated and used in the design and conduct of research programs at the community level. Likewise, the same rationale should be used in evaluations at the ecosystem level. Using this approach means that ecological data, when combined with economic and sociological considerations, will provide a better insight into the total consequences and costs of an environmental perturbation.

Much of the funding for environmental protection is spent on research, during crises and after the fact, to evaluate the effects of activities on the environment. A systematic research program that anticipates possible crises could reduce future environmental problems and costs, including after-the-fact research.

EFFECTS OF PRUDHOE CRUDE OIL SPILLS ON COASTAL TUNDRA PONDS

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INTRODUCTION

The discovery of 10 billion barrels of oil at Prudhoe Bay and the completion of the Alaska pipeline later this year will initiate large scale extraction and movement of crude oil across the Arctic North Slope of the Brooks Range. In massive projects of this kind, small errors can result in large spills. Large spills of gasoline or diesel fuel have occurred in Barrow, Alaska and in Alyeska camps at Happy Valley, Galbraith Lake and Prudhoe Bay during the past two years. A break in the pipeline which drained only one mile of pipe between cut-off valves could release as much as 1878 m^3 of oil if valves were closed immediately. Additionally, renewed exploration for oil is going on across the old Naval Petroleum Reserve No. 4 and offshore in Prudhoe Bay and spills are almost certain to occur there as well. Until recently we have had no experimental evidence of what ecological effects oil spills might have. Much early work in Arctic Alaska involved the effects of oil on terrestrial vegetation and permafrost documenting the delicate balance between the two. A small aquatic oil spill evaluation project was begun by the U.S. International Biological Program, Tundra Biome in 1970. It is from that experience that the present project funded by Energy Resources Development Administration was begun in 1975.

Several problems have hampered evaluation of oil spill effects on natural aquatic ecosystems. First, the studies have been too brief to document recovery. Secondly, the species present and their life histories were almost unknown, except for the phytoplankton and zooplankton (Hobbie 1973). Following the IBP studies, it was impossible to predict the recolonization potential for most invertebrates if mortality did occur. The present studies have allowed us to describe the many species and their life histories, resolve the problem of initial toxicity, determine sensitivity of several life stages, and follow the recovery of a pond biota following a spill. Further, the rate and degree of oil degradation and weathering of crude oil under arctic summer conditions have been followed.

TECHNICAL DISCUSSION

Prior to the ERDA program on freshwater ecosystems, most of the data available from experiments in the arctic evaluated the effects of crude oil leakage on marine systems, e.g., in Cook Inlet or the Gulf of Alaska (Kinney, Button, and Schell, 1969; Robertson et al., 1973; Button et al., 1973; Moore et al., 1974). Only a few studies had examined effects of oil in arctic freshwaters (Arhelger and Button, 1972; Barsdate, Alexander and Benoit, 1973; Atlas, 1973). Much of the work documenting the effects of oil spills on arctic and subarctic lakes was completed by Environment Canada and others (Dickman, 1971, Brunskill et al., 1973; Snow and Scott, 1975; Snow and Rosenberg, 1975A; 1975B; Roeder et al., 1975; Snow and Brunskill, 1975). Some similarities exist between the effects of Canadian Pembina and Norman Wells crude oils from the MacKenzie Delta and the effects of Purdhoe crude oil, but significant differences also exist. The differences in response were presumably caused by difference in composition of the oil, in latitude of experimental sites, and in type of aquatic ecosystems.

In the Canadian subarctic spills, observations of the effects on aquatic biota in a range of doses from 0.03 to 9.1 ml/liter have lead to several generalizations:
1) Rapid volatization resulted in the loss of toxic compounds within hours, e.g., 30-40% loss of volume of crude oil in the first day (Snow and Rosenberg, 1975B). 2) Primary productivity of algae often showed immediate inhibition in the first two days, with reductions lasting no longer than the first summer. 3) Phytoplankton and periphyton biomass increased in oiled sections of lakes in the Northwest Territories. 4) Species composition changes as blue-green algae became dominant especially in the periphyton which grew profusely. 5) Large numbers of invertebrates and small fish were trapped and killed in floating oil scum.

We will show how oil weathers and its effect on the components of the biota of two small shallow (0.2 m) polygonal thaw ponds located at 71° N. Lat. near Barrow, Alaska. The ponds are very similar to the ponds near Prudhoe Bay in which the probability of an accidential crude oil spill is much higher. About 10 liters of oil/m^2 were experimentally applied to Pond E in July 1970; 0.24 liters/m^2 were applied to Pond Omega in July 1975. The present program has followed the recovery of the older spill, the immediate toxicity and recovery of the smaller spill, and included experimental analysis of the solubility, weathering and toxicity of crude oil.

PROGRAM DISCUSSION

Weathering of Crude Oil

Oil degradation was measured by loss of freon or hexane extractable materials from a series of cores suspended in Pond Omega, each of which had an equivalent of 420 ml/l (1.2 ml/l) of Prudhoe crude oil. During the first day 10% of the oil disappeared. Subsequently, extractable oil degraded at a rate of 3.1% per day during the first 40 days. Although there was some difference between the loss of oil in $HgCl_2$-killed and experimental cores (6% after 40 days), by the second summer 58% of the initial inoculum was recovered and no difference existed between Hg-killed and experimental cores. No significant differences in class composition in the saturate fraction, aromatic fraction, benzene-soluble asphaltene fraction, benezene-insoluble asphaltenes, and nitrogen-, sulfur-, or oxygen containing fractions (Jobson et al., 1972) could be seen between fresh oil, 13 day old, 1 year old and 5 year old weathered oil from the ponds. In the saturate fraction after 45 days no alkanes shorter than C_{13} remained; after one year no alkanes shorter than C_{15} remained. Bacterial induction to use complex hydrocarbons was long under ambient summer arctic temperatures. It took 125 hours before any mineralization of hexadecane could be detected by $^{14}CO_2$ release. The presence of crude oil appeared to inhibit mineralization of ^{14}C-hexadecane even more. Thus the degradation of crude oil is a slow process in the arctic proceeding as much by abiotic weathering as by bacterial mineralization. All types of compounds in crude oil appeared to disappear at the same rate so that the composition of the residual did not vary significantly with time (Miller et al., In Press).

Toxicity to Phytoplankton and Primary Production

Reduction of ^{14}C-production was monitored in bottles after adding oil onto the surface of the enclosed water, with and without violent mixing of the oil and water. Unmixed, complete inhibition of photosynthesis of pond algae did not occur until 80 µl of oil/liter of pond water had been added; however, with mixing only 30 µl/liter was 100% inhibitory. Mixing increased the measured solubility Prudhoe crude oil about 10-fold at any temperature.

In a whole pond application of oil on Pond Omega (240 ml/l or 1.2 ml/l.), primary production was inhibited for 6 days compared to a control Pond C (Figure 1). However, during those 6 days the algal biomass increased to greater than that in the control pond and remained higher on six of seven dates during the next 46 days.

In a set of 18-liter subponds filled with Pond C water on June 25 four treatments were set up: treatment 1 was the control with normal zooplankton densities (2 Daphnia middendorfiana and 1 Branchionecta paludosa per liter); treatment 2 lacked zooplankton; treatment 3 received normal zooplankton and crude oil at 1 ml/l.; and treatment 4 lacked zooplankton and received crude at 1 ml/l. Within five days several key species had been eliminated or reduced by over 90% in density in oil treated subponds (Table 1). They were Rhodomonas sp., Ochromonas sp. and Mallomonas sp. Some very short-term effect of the oil greater than the effect of eliminating zooplankton grazing pressure must have caused the changed composition, presumably a toxicity of the oil.

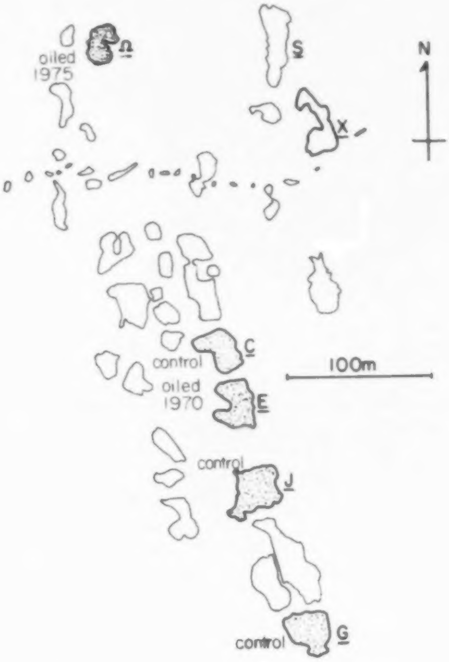

Figure 1. I.B.P. Tundra Biome study site, Aquatic Program.

Effect on Emergent Vegetation

The dominant sedge surrounding the ponds was Carex aquatilus, which formed thick beds in the littoral zone. Floating oil became lodged in the dead water between the fronds on the downwind side of the ponds following whole pond spills. Few quantitative studies on macrovegetation were done; however, the data show no decrease in plant biomass even in the zones of the heaviest oil tar accumulation. Since the sedges grow from a central meristem with the older leaves located on the exterior, the fronds quickly grew above the water level in early summer leaving the old leaves at the base blackened with oil. Only in our heaviest spill on Pond E (10 l/m^2) did the depth of the residual oil tar on the downwind shore prevent shoot emergence. Although subtle effects may have occurred, they were not evaluated and the littoral zone remained intact.

Toxicity to Zooplankton

Following the 1970 spill in Pond E all zooplankton were eliminated and no successful reproduction of zooplankton took place until five years

TABLE 1: PARTIAL PERCENTAGE COMPOSITION BY DENSITY OF PHYTOPLANKTON GENERA WHICH INCREASED OR WERE ELIMINATED IN SUBPOND EXPERIMENTS, POND C, SUMMER, 1976.

Genus	Subpond	Pond C	Treatment 1			Treatment 2			Treatment 3			Treatment 4			Pond C
	Date	day 0	5	15	41	5	15	41	5	15	41	5	15	41	41
Chlamydomonas spp. (C.)		0.16	2.2	1.4	14.8	6.3	2.9	0.5	7.9	2.4	24.1	9.5	9.1	20.9	7.7
Rhodomonas sp. (Cryp.)		64.1	48.3	48.0	1.9	35.2	9.9	--	6.5	2.1	0.3	5.3	--	--	present
Ochromonas spp. (Chr.)		--	2.8	1.4	5.5	7.4	7.9	3.7	--	21.4	10.3	--	31.8	--	--
Mallomonas sp. (Chr.)		3.1	4.1	1.4	13.0	4.3	2.0	--	--	1.6	--	--	0.9	2.0	--
Uroglena spp. (Chr.)		--	--	--	--	--	--	2.1	--	--	12.9	--	--	24.3	--
Dinobryon sp. (Chr.)		--	--	--	--	--	--	83.4	--	--	--	--	--	--	15.3
Oscillatoria spp. (Cyan.)		--	--	--	--	--	--	--	--	--	27.9	--	--	27.9	--
Trachelmonas spp. (Eug.)		--	--	--	--	--	--	--	3.3	--	--	1.7	--	1.3	7.7

Other species of Chrysophyta (*Chromulina* spp. and *Chrysococcus* spp.) and Cryptophyta (*Chryptomonas* sp. were present in all treatments through the experimental period and were frequently the dominants. Only the species which arose or were eliminated are presented in the preceeding table.

Abbreviations: C = Chlorophyta, Cryp. = Cryptophyta, Chr. = Chrysophyta, Cyan. = Cyanophta, and Eug. = Euglenophyta, -- = none detected.

had passed. Following the oil spill in Pond Omega in 1975, mortality again occurred. The sequence in which the species died exactly followed the response of the several species in separate aquarium exposures to the same doses of oil. The zooplankton were placed in cages at the bottom of the aquarium so that no chance of physical contact could have occurred except by soluble products (conducted by J. O'Brien, Kansas State Univ.). The most sensitive species was Branchionecta, the fairy shrimp; then Daphnia middendorfiana and least, the copepods (Figure 2). Following a controlled spill 10 July, fairy shrimps were reintroduced into Pond Omega and Pond C control 6 days and 14 days after the spill in netting-ended containers, all died by 7 days. After 14 days post spill, Heterocope survived the same 4 days exposure which killed Daphnia. Thus the soluble fraction, composed most likely of aromatic compounds, was toxic to zooplankton in aquarium experiments and two whole pond applications.

Retesting these animals in a similar set of experimental chambers with a different batch of crude oil showed no toxicity a year later. Apparently, different wells in the Prudhoe oil field produce oil of varying toxicities. Or the practice of extracting naphtha and diesel by distillation and reinjecting the heavier nonvolatile components back into the well may have changed the apparent toxicity of the oil.

Toxicity to Invertebrates

Invertebrates which were near the surface of the water became trapped by the floating oil scum and mechanically retained. Groups like the surface mating chironomids (Diptera) and all insect larvae which lived or fed on the emergent sedges in the littoral zone were likely to be exposed if

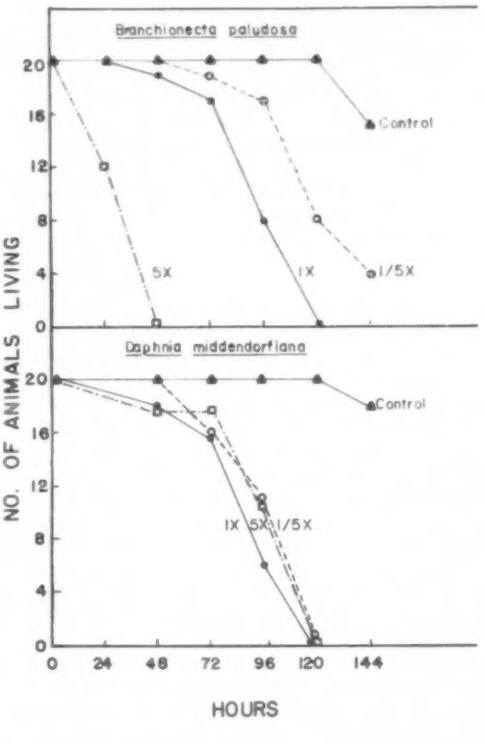

Figure 2. Survival of fairy shrimp Branchionecta paludosa and Daphnia middendorfiana bottom to oil at dose 1/5 x, 1 x, and 5 x the dose in Pond Omega.

the wind blew the floating oil on them. After the massive 1970 experimental spill, many fourth instar chironomid larvae were noticed dead on the bottom of the pond. However, no obvious larval mortality was observed in the 1975 spill on Pond Omega at 1/40 the dose rate.

Laboratory experiments on oil toxicity were conducted in glass or plastic cages placed at the bottom of aquaria containing 14 liters of pond water on which was floated crude oil at three dose rates, with unoiled controls. Twelve to fifteen day observations were made on Nemoura (stonefly), Limnephilus (caddisfly), Turbellaria (flatworm), Physa (snail), Agabus (Beetle), Micrasema (caddisfly), and four genera of midge larvae (Trichotanypus, Procladius, Chironomus, and Tanytarsus). In most cases, mortality in control aquaria was equal to or greater than mortality in oil-treated aquaria. Control mortality was often high caused in part by disruption of normal environmental conditions for the species during the test. Several of the kinds of insects tested metamorphosed in the field during the toxicity testing period. In no case was there rapid or complete mortality.

Field Experiments--Phytoplankton-Zooplankton

In the series of 18 liter subponds placed in Pond C set up with treatments of plus and minus zooplankton and plus and minus oil at 1 ml/l., the zooplankton all died within five days in all oil treatments. The thaw ponds and, initially, the subponds were dominated by phytoplankton composed of Rhodomonas, a crytophyte, by Chromulina, Chrysococcus, both chrysophytes and by Chlamydomonas, a chlorophyte (Table 1). After the 1970 spill on Pond E and after the 1975 spill on Pond Omega, the phytoplankton became dominated by a new Chrysophyte, Uroglena, not normally found in these ponds (Miller et al., In Press).

Because the zooplankton grazers were killed within 5-6 days following the spill or application of oil on the ponds or subponds, the question was to what extent the change in algal composition was caused by oil toxicity or to the elimination of grazing pressure. In the series of subponds, Rhodomonas sp. was reduced by 90% in the oil treated subponds after five days; however, in treatment 2 lacking zooplankton it was reduced 50% compared to the control in 15 days. Thus the immediate oil-related treatment contributed directly to the elimination of Rhodomonas. However, the elimination of the zooplankton in treatment 2 led to the elimination of that key species after 41 days. At that time in the control subponds, treatment 1, the phytoplankton were dominated by the chrysophytes, Chromulina, Chrysococcus and Ochromonas; however no new species had become common and no species present initially had been eliminated completely (Table 1). In oil treated subponds dominants included Chlamydomonas, Uroglena and a non-heterocystous blue-green algae, Oscillatoria. In the zooplankton-free subponds, treatment 2, a Dinobryon sp., chrysophyta, became the dominant (83% by number).

Following the application of oil the algal biomass increased dramatically in zooplankton-free, treatment 2. As the inhibition of primary production by oil lessened, the algal biomass in those subponds treated with oil increased to the same level as that in treatment 2 after 41 days. Thus, the effect of oil in eliminating the zooplankton allowed the phytoplankton to increase in biomass, incorporating all available nutrients into cell bodies. The reduction in grazing pressure changed the composition of the phytoplankton including the elimination of Rhodomonas (Figure 3). The addition of oil changed the dominants in subponds, allowing a filamentous, non-heterocystous blue-green algae to become common, similar to what the Canadians found in subarctic lakes (Table 1).

No filamentous blue-green algae were found in the thaw ponds receiving whole pond application of oil at the same rate. The algal biomass did increase in 1975 following the spill on Pond Omega, but not nearly as much as in the subponds. The bottom sediments in these tundra ponds reversibly absorb reactive phosphorus maintaining the concentration less than 3 μg P/l on the average (Prentki 1975). Thus even following the death of the zooplankton in the oil-treated thaw ponds, nutrients in solution were bound into the sediments. In the subponds receiving oil, nutrients maintained in solution by the grazing and excretion by zooplankton became locked into algal biomass. Apparently, no nutrients in excess of those already in the water and in the seston when the subponds were filled were available because the algal biomass became equivalent in the zooplankton-free and oil-treated subponds. The apparent resistance of thaw ponds to the eutrophication-like effects from oil spills is primarily caused by the sorbtion-equilibrium of phosphate with the iron-rich surface sediments. Most of the changes in algal composition observed were in part caused by the elimination of grazing pressure and by the selectivity of the oil.

Field Experiments--Pond Benthos

Observations on the 1970 experimental spill on Pond E and the 1975 spill on Pond Omega showed changes in larval species composition and changes in the proportion of 4th instars emerging following the spills compared to control Pond J and G (Figure 1, Table 2). Changes in composition persisted to some degree for at least 6 years after the 1970 spill. Pond E yielded about as many adult midges per unit area as the adjacent Pond J, both at relatively high concentrations. However, the species emerging were different. The largest qualitative differences between Pond E in comparison to J and G in the open bottom were the small number of Tanytarsus gregarius (Tanytarsini) and the large numbers of Psectorocladius psilopterus-gr. spp. (Orthocladiinae), collected in Pond E emergence traps. Pond E also had larger populations of Tanypodinae and Chironomus than untreated ponds. Similarly, Pond E had fewer Paratanytarsus, Tanytarsus and Constempellina (Tanytarsini) and more Cricotopus (Orthocladiinae) and Trichotanypus (Podonominae) in traps than the two untreated ponds. Larval samples from open bottom in the early summer in 1975 and 1976 (Table 3) showed the same high relative density of Orthocladiinae and lesser densities of Tanytarsini in Pond E compared

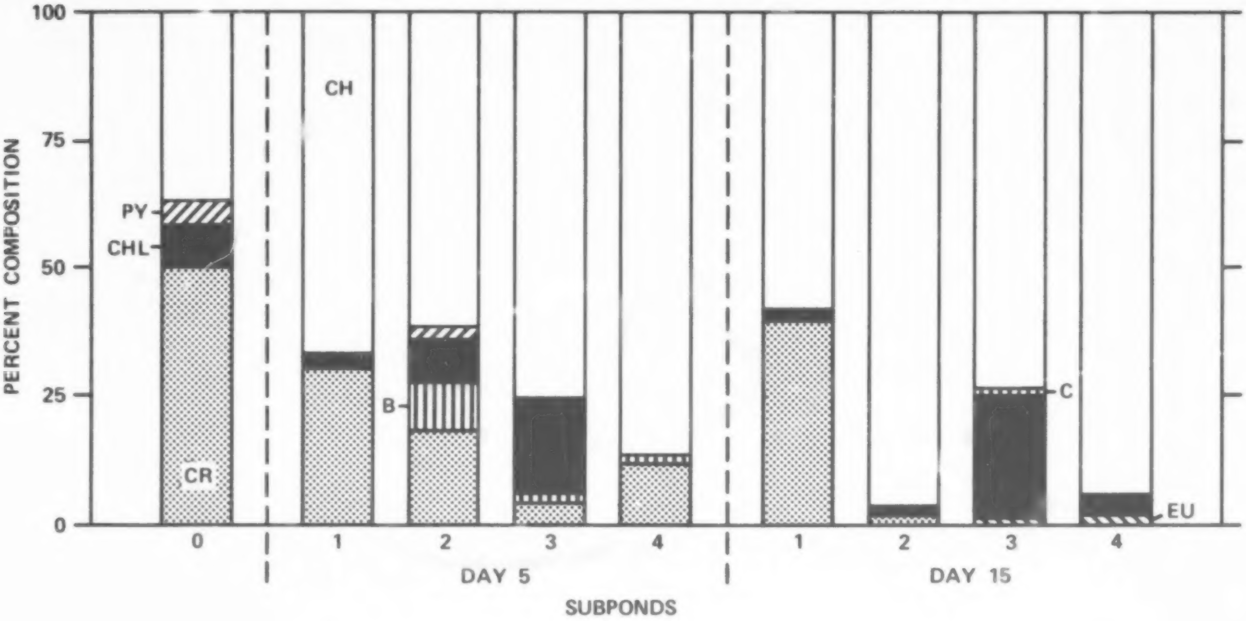

Figure 3. Percentage composition of algal phyla by algal volume in Pond C and subponds at 5 and 15 days following the application of oil. Treatment 1 included natural zooplankton, treatment 2 lacked zooplankton, treatment 3 included zooplankton initially and was dosed with oil (1ml /1.), and treatment 4 lacked zooplankton and was dosed with oil.

TABLE 2: CHIRONOMIDAE EMERGING FROM TWO HABITATS IN FOUR PONDS IN 1976, ARRANGED IN ORDER OF DECREASING NUMBER PER UNIT AREA.

Habitat	Pond			
	Omega	E	J	G
Open Bottom	*Corynoneura* spp.	*Psectrocladius* sp. 1	*Tanytarsus inaequalis*	*Tanytarsus inaequalis*
	Paratanytarsus	*Psectrocladius* sp. 2	*Paratanytarsus*	*Corynoneura* spp.
	Tanytarsus gregarius-gr.	*Tanytarsus inaequalis*	*Constempellina*	*Cladotanytarsus*
	Chironomus pilicornis-late	*Corynoneura* spp.	*Tanytarsus gregarius*-gr.	*Chironmus pilicornis*-early
	C. pilicornis-early	*Procladius* sp.	*Cladotanytarsus*	*Constempellina*
	Stictochironomus	*Trichotanypus*	*Corynoneura*	*Trichotanypus*
	Procladius sp.	*Chironomus pilicornis*-late	*Chironomus pilicornis*-early	*Procladius gretis*
	Procladius gretis	*Cricotopus tibialis*	*C. pilicornis*-late	*C. pilicornis*-late
	Derotanypus aclines	*Tanytarsus gregarius*-gr.		
Carex	*Corynoneura* spp.	*Trichotanypus*	*Paratanytarsus*	*Corynoneura* spp.
	Procladius gretis	*Psectrocladius* sp. 2	*Corynoneura* spp.	*Paratanytarsus*
	Tanytarsus gregarius-gr.	*Cricotopus tibialis*	*Tanytarsus gregarius*-gr.	*Trichotanypus*
	Paratanytarsus	*Corynoneura* spp.	*Tanytarsus inaequalis*	*Derotanypus alaskensis*
	Derotanypus aclines	*Cricotopus perniger*	*Derotanypus alaskensis*	*Procladius gretis*
	Procladius sp.	*Derotanypus alaskensis*	*Constempellina*	*Cladotanytarsus*
	Chironomus (Camptochironomus)	*Procladius gretis*	*Trichotanypus*	*Tanytarsus inaequalis*
	C. pilicornis-early	*Cricotopus* sp. 3	*Psectrocladius* sp. 2	*Constempellina*
	C. pilicornis-late			

TABLE 3:

BENTHIC FAUNAL COMPOSITION IN OPEN BOTTOM AREAS OF THREE TUNDRA THAW PONDS NEAR BARROW IN 1975 AND 1976, EXPRESSED AS NUMBER PER SQUARE METER. SAMPLES WERE COLLECTED BEFORE MOST SPECIES HAD BEGUN TO EMERGE IN EARLY SUMMER.

Taxon	Pond J 1975	Pond J 1976	Pond E 1975	Pond E 1976	Pond Omega 1975	Pond Omega 1976
Chironomidae						
Chironomus spp.	17,400	7,690	2,400	4,800	1,430	767
Stictochironomus	0	0	0	0	447	0
Tanytarsus spp.	17,800	11,500	179	386	4,460	4,230
Paratanytarsus	1,040	1,730	356	1,440	802	98
Cladotanytarsus	2,460	1,540	267	98	0	98
Procladius spp.	1,890	961	981	674	88	963
Derotanypus spp.	93	0	44	190	0	0
Trichotanypus	0	0	0		88	0
Psectrocladius spp.	0	0	4,100	478	179	0
Cricotopus spp.	0	0	535	0	0	0
Corynoneura	0	0	88	0	0	0
Other Orthocladiinae	190	0	179	98	88	190
Oligochaeta						
Enchytraeidae	378	192	267	98	267	98
Tubificidae	3,210	769	447	2,590	267	576
Total Macroinvertebrates	44,500	24,400	10,200	10,900	8,120	7,020

to Pond J. Densities of Oligochaetes were not detectably different between the ponds. In contrast, the ratio of adults emerging to larval densities of Procladius (Tanypodinae) and Chironomus and the total number of adults were higher in Pond E than in Pond J (Figure 4, Table 2). Recovery in Pond E appears to be well advanced, but natural species balances have yet to be established.

Qualitative sweep samples from the Carex habitat in the oil-treated ponds and two untreated ponds suggested other qualitative differences between Pond E and untreated ponds. In particular Trichoptera (caddisflies) and Plecoptera (stoneflies) were abundant in samples from untreated ponds, but rare or absent in Ponds E and Omega. Instead, Pond E yielded large numbers of Trichotanypus larvae and the Pond Omega sample essentially lacked larger insects in 1976, one year after the spill (Table 4).

Emergence in Pond Omega was quite small (Figure 4). All species were suppressed, but Chironomus appeared to be less affected than other midges, and consequently accounted for a larger proportion of total emergence (Table 2). In contrast benthic samples indicated that little overall change took place between pre-spill populations (1975) and post-spill ones (Table 3). The number of samples which have been processed is not yet sufficient to determine whether apparent reductions in Paratanytarsus and Stictochironomus were real. Still, it is obvious that Tanytarsus larval populations were not diminished. If the response of Pond Omega to the spill follow those of Pond E, changes in composition may take another year or two to become evident in larval populations. Some suppression of recruitment of Tanytarsus in 1975 was suggested by a low proportion of early instars in June, 1975 (19% instar II) as compared to June, 1975 (58% instar II) (Table 3). The experimental spill in 1975 was conducted after emergence of one of the Tanytarsus species.

The effects of oil on benthos vary with taxa and habitat. Among the Carex shoots, a large amount of biomass due to the nondipteran insects appears to be removed by a mixture of entrapment in floating oil, oil adhering to the vegetation, and perhaps toxicity to older and newly hatched larvae. In Pond E, some of this biomass seems to be replaced by Trichotanypus, a midge larva. The success of Trichotanypus may be due to reduced competition from other scraping and grazing insects, reduced predation or changes in the epiflora of the macrophytes.

In the open bottom, direct toxicity is apparently negligible, but reproduction and recruitment of the midges is hampered at metamorphosis, and perhaps just after the larvae hatch. Preliminary examination of egg trap results suggested that an overwhelming majority of egg masses of all species are laid or rafted to the downwind shore. Repopulation of the center must depend on larval movements. Since the oil scum in the treated

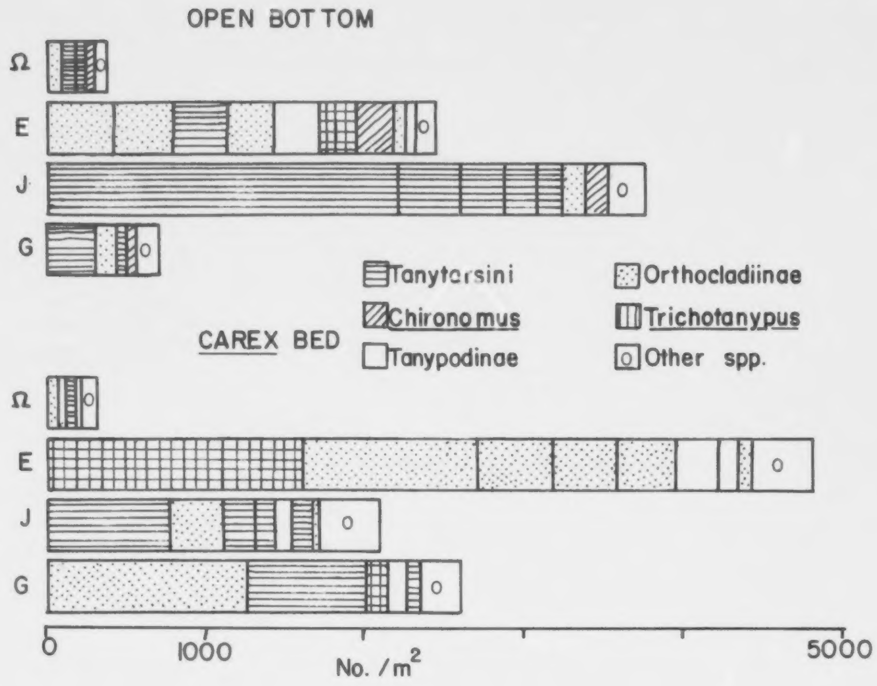

Figure 4.

Quantity and composition of Chironomidae emerging from the two principal habitats in four ponds in 1976.

TABLE 4:

BENTHIC FAUNA FROM QUALITATIVE SWEEP-NETTING IN FOUR PONDS IN MID-JULY 1976, LISTED IN ORDER OF DECREASING ABUNDANCE.

Pond			
J	S	E	Omega
Nemoura	*Micrasema*	*Trichotanypus*	*Paratanytarsus*
Paratanytarsus	*Nemoura*	*Paratanytarsus*	*Procladius*
Limnephilus	*Paratanytarsus*	*Derotanypus*	*Lebertia*
Micrasema	*Limnephilus*	*Procladius*	*Agabus* (Larvae & adults)
Procladius	*Agabus* (Larvae & adults)	Enchytraeidae	
Physa	*Procladius*	*Lebertia*	
Agabus (Larvae)	*Chrionomus*		
Lebertia	*Tanytarsus*		
Enchytraeidae	Enchytraeidae		

ponds also moved to the downwind shore, a large proportion of newly hatched larvae are exposed to relatively high oil concentrations and many may die before dispersing. It should be noted that at least half of oil-treated egg masses produced larvae which behaved normally in the laboratory. Direct field observation showed that the oil scum did not prevent emergence of pupae when they reached the surface; however, larval metamorphosis in Pond Omega in 1976 was suppressed. It is now clear that both surface-mating and aerially mating midges are suppressed at metamorphosis before mating can occur.

The critical phase then is recovery of midge populations, which is most directly related to dispersal capability of the different species. Recovery of larval populations in Pond E appeared to correspond to the ability of the females of each species present to fly to ponds other than their home pond.

A consequence of the long life cycles of midge larvae (2-7 years) and this new hypothesis is that spills of oil over large areas of tundra could have catastrophic and long-lasting effects on midge populations in the ponds. If there were no unexposed local reservoir populations to recolonize the oil-affected ponds, recolonization of flightless and weak flying species must occur gradually from much farther away and would therefore be slower. Adult midges live only a few days, and the period after mating and before death is even shorter, constricting still more the potential for recolonization from a distance. The oil-treated ponds in the Barrow area are virtually surrounded by unaffected populations, and therefore do not provide an accurate representation of the effects of more extensive spills.

CONCLUSIONS

Having followed the initial changes that occur at several trophic levels in tundra pond ecosystems after an oil spill with Prudhoe crude and their recovery over the next 6 years, we are beginning to understand the implications of oil on the biota in these ubiquitous ponds. Most important is the fact that the compositional changes are profound and long-lasting. After 6 years, the zooplankton (Daphnia) had just been observed to survive through the entire summer and reproduce. Similarly Rhodomonas, a phytoplankter, was also observed in Pond E for the first time since the spill, presumably in response to the reestablishment of populations of grazers. This food chain dependent maintenance of the algal composition considered "normal" for these ponds is a documentation of the interrelatedness between trophic levels. The long-term effects of the oil seemed to have been upon the survival and reproduction of the zooplankton in these ponds.

The species composition in the chironomids and other insects similarly remained altered for years. Although total densities were high, the total emergence of adults was very low for two years, at least. How the oil acts in this effect and in survival of zooplankton is not known, but since mechanical contact with floating oil was not involved, it must be an effect of soluble products or of oil transferred into the sediments.

Thus the examination of the classical toxicity of the component species as in bioassays, would predict the effects of the oil to be short-lived. Two groups of animals, the zooplankton and the chironomids, showed an apparent sublethal effect which stopped reproduction or maturation to sexual maturity. Our preliminary analysis based on the bioassays similar to those used in preparing impact statements, would not have predicted the long recovery times of species composition observed.

The rates of algal primary productivity and epibenthic algal production (Stanley 1976), benthic respiration (Miller and Reed 1975), bacterial density and activity and total secondary benthic production returned to near normal levels long before the species composition had been reestablished. The long, multi-year life cycles for the chironomids in the arctic (5-7 years) is in part responsible for the slow recovery. A single parthenogenic reproduction per year in the common Daphnia similarly meant that these populations were not capable of rapid recovery. Thus, although the pond carbon dynamics and nutrient chemistry appeared to have recovered quickly, marked species compositional changes remained. Alteration of the species composition at the several trophic levels was determined by the species life history, sensitivity to the oil, and alteration in the trophic level above the one of concern.

Since the nutrient equilibria and permafrost relations of these shallow ponds is dependent upon the mud water interface, the best treatment for small spills might be a low disturbance cleaning such as soaking up thick scum before it becomes tar-like. Physical damage to the shore, vegetation and pond bottom during the ice-free season would cause as much damage ecologically as leaving the spill untreated. Certainly detergents, dispersants and coagulants might have worse potential effects than the oil.

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MECHANISMS OF SULFUR DIOXIDE RESISTANCE IN GREEN PLANTS

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INTRODUCTION

Green plants are more sensitive to acute exposure to SO_2 than are mammals, including people. While 1 - 5 ppm SO_2 elicits only the most subtle of effects in mammals, even after repeated exposure (1), many plant species will sustain massive damage in the form of necrotic lesions covering a substantial percentage of the leaf area, following a single relatively brief exposure in the same concentration range (2). Since SO_2 reduces crop yield in proportion to the leaf area destroyed (2), the most serious potential consequence of an elevation of atmospheric SO_2 may be the impact on agricultural productivity, especially in areas near large concentrations of coal burning facilities.

The mechanism by which SO_2 injures plants is unknown. Because of the reactivity of SO_2, there is no shortage of hypothetical targets. Sulfite or bisulfite, the ions formed when SO_2 dissolves in water, reacts with aldehydes and ketones of sugars, with the disulfide bonds of proteins, and with groups in nucleic acids as well (3). Presumably in this vast array of potential targets there is a most sensitive essential molecule, the reaction of which precipitates the chain of events culminating in injury. Numerous enzymes are known to be sensitive to SO_2, but none has yet been shown to be causally related to injury. In addition to such biologically abnormal reactions being candidates for the injury mechanism, it is possible that injury is a consequence of the fact that sulfite in a bound form is a normal intermediate in the pathway of sulfate assimilation in plants (4). Furthermore, plants contain enzymes which catalyze the reduction of free or bound sulfite to free or bound hydrosulfide, respectively, and either form of hydrosulfide can be used in the synthesis of the two sulfur-containing amino acids, L-cysteine and L-methionine. Perhaps the damage done by SO_2 results from overloading the normal sulfur pathway.

It has been well known for more than 50 years that there is about a 10-fold range of differences in sensitivity to acute exposure to SO_2 among plant species (5). Just as the mechanism of injury is unknown, the mechanisms of resistance are also unknown. It is convenient to divide possible resistance mechanisms into two classes: resistance due to a lower rate of SO_2 absorption, and resistance due to a lower rate of occurrence of the biochemical lesion after the SO_2 has been absorbed by the plant. Because SO_2 is a gas, and gases are known to enter plants largely through the thousands of adjustable pores called stomates which exist on the surface of each leaf, it has long been hypothesized that genetically or phylogenetically determined resistance differences are probably due to uptake differences which in turn would be expected to reflect differences in stomatal behavior or number (2). This hypothesis, however, has not been tested experimentally.

About eighteen months ago, my colleagues, Ray A. Bressan and Lloyd G. Wilson, and I began a search for new clues to the mechanisms of injury by SO_2 and resistance to SO_2 in plants. We reasoned that such clues should turn up in studies of the comparative physiology and biochemistry of genetically or phylogenetically related plants which differed in resistance to SO_2. We elected to concentrate our efforts on the Cucurbitaceae (cucumbers, squashes, melons, etc.) for several reasons: 1) a wide range of sensitivity to SO_2 was evident within this family in the old surveys (5), 2) these plants grow rapidly and have large leaves, which makes them convenient for growing, fumigating and assessing injury, 3) because they have been cultivated and bred throughout the globe, a large pool of genetic variation exists, and 4) a cucumber breeder on the MSU faculty agreed to provide advice and to collaborate in genetic studies.

TECHNICAL DISCUSSION

Our first objective was to identify within a species if possible, pairs of cultivars which differed in sensitivity to SO_2, and to distinguish those cases in which the resistant member of such pairs has lower rates of SO_2 absorption than the sensitive member, from those cases in which there was no apparent difference in absorption rate. We intended to do comparative biochemical studies on pairs with equal SO_2 absorption rates. In order to perform these studies, an apparatus was constructed around a Monitor Labs Model 8450 Sulfur Analyzer. In the apparatus, air containing SO_2 was diluted to the desired concentration with SO_2-free air and was passed through a plexiglas fumigation chamber big enough to hold several plants. The air stream after suitable dilution was monitored by the sulfur analyzer alternately before and after the fumigation chamber. The rate of SO_2 absorption was calculated from the difference in SO_2 concentration before and after the chamber at near-steady state. At the end of the fumigation, the leaf areas were traced, and the tracings were cut out, weighed, and the leaf area was calculated. Twenty four hours later, the percent of leaf area which had become necrotic was estimated. In a typical experiment, air containing 2 ppm SO_2 flowed at 9 L min^{-1} through the 125 L fumigation chamber, which contained 1 plant with 8 leaves having a total surface

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area of about 400 cm^2. A typical plant would absorb about 15% of the SO_2 from the flowing air. This corresponds to an absorption rate of about 250 pmoles min^{-1} cm^{-2}. Up to a few ppm SO_2, the absorption rate was approximately proportional to SO_2 concentration, as expected for a diffusion-limited process. The apparatus could detect a change of 20 pmoles min^{-1} cm^{-2} within seconds and measure it within 7 minutes. Before returning the air to the ambient atmosphere, SO_2 was removed by bubbling the air stream through water. The apparatus has been remarkably trouble-free and dependable, so that it has been possible to run experiments around the clock week after week, the only down time being that required to change the plants in the fumigation chamber.

Two cultivars of Cucumis sativus (cucumber) and two cultivars of Cucurbita pepo (squash and pumpkin) were found to differ from each other in sensitivity to SO_2 when compared on the basis of the concentration of SO_2 to which they were exposed (Fig. 1). The most resistant cultivar (pumpkin) required about a 5-fold higher exposure than the most sensitive cultivar (cucumber SC 25) for equivalent injury. However, all four cultivars had about the same sensitivity when compared on the basis of how much SO_2 they had absorbed. The amount of injury sustained by each of these cultivars at a certain exposure concentration of SO_2 varied approximately in proportion to the rate of SO_2 absorbtion by the cultivar (Table 1). I believe that this is the first demonstration that species and varietal differences in sensitivity to SO_2 can largely be accounted for by their SO_2 absorption rates.

Previous workers have noted that the young leaves of many plants are more resistant to injury by SO_2 than are the mature leaves (2). We also encountered this phenomenon, and so we asked the question: are young leaves resistant because they absorb SO_2 at a lower rate than mature leaves? Fumigations were performed on plants with either the upper or the lower 50% of the leaves intact, and both SO_2 absorption and degree of injury were determined. Young leaves were far less injured than mature leaves that had absorbed a comparable amount of SO_2 (Fig. 2). The pattern was the same for the four cultivars studied, and young leaves were more alike, regardless of cultivar, than were young and mature leaves of the same cultivar. Since the young leaves absorb the SO_2 but are not severely injured by it, there must exist a biochemical difference between young and mature leaves that minimizes the opportunity for at least one of the reactions leading to injury. I believe that this is the first indication that plants possess a resistance mechanism that can operate after the SO_2 has been absorbed.

The discovery several years ago by de Cormis that plants exposed to injurious concentrations of SO_2 emitted H_2S (6), raised the question of whether or not H_2S was causally related to injury due to SO_2. In the course of studying this phenomenon, we discovered that plants fed sulfate also emit H_2S. By mechanically injuring the roots, or feeding detached leaves through the cut petiole, it is possible to induce leaves in bright light to emit H_2S in response to sulfate at rates comparable to or exceeding those from leaves treated with bisulfite in dim light. While the leaves treated with bisulfite developed the injury symptoms characteristic of exposure to SO_2, those treated with sulfate did not. Therefore, H_2S is not causally related to injury from SO_2 exposure. H_2S emission reached maximal rates of the order of 50 pmoles min^{-1} cm^{-2}, and continued for several hours. At that rate, a 50 cm^2 cucurbit leaf could generate 1 ppm H_2S in 60 ml air every minute. These observations lead me to suggest that terrestrial plants may be a previously unappreciated source of atmospheric sulfur. The origin of about half of atmospheric sulfur is unknown, although it has been thought likely to originate as H_2S from decaying biological material (7).

PROGRAM DISCUSSION

One way to minimize the impact of SO_2 pollution on crop productivity would be to plant resistant cultivars nearest a source. Needless to say, resistant cultivars of agriculturally important crops are a prerequisite to this approach. Although a few such cultivars are known (8), it is probably a good idea to begin to breed for resistance to SO_2 in sensitive species now, in order to have a sufficient collection of resistant cultivars if and when they are needed in the future. Our results suggest that there is a high probability that the outcome of a simple screen for SO_2 resistance is very likely to be selection of cultivars which take up less SO_2 than their sensitive relatives. However, if SO_2 absorption rate is altered by altering stomates, there is the danger that fixation of CO_2 and transpiration of water, which are mediated by the stomates, will be disturbed in an unfavorable way in such cultivars. Is it possible to have cultivars with a reduced rate of SO_2 absorption, but with normal rates of CO_2 fixation and water transpiration? If such a combination proves to be impossible, then screens should be set up for cultivars with resistance that comes into play after the SO_2 has been absorbed. Might it not be possible to breed plants in which a higher percentage of the leaves retain the biochemical resistance characteristic of young leaves?

We hope to explore all of these questions in the cucurbits. We are beginning to study the relationships between SO_2 absorption, CO_2 absorption and water loss. We are also beginning some genetic analysis of SO_2 resistance. Cucumber SC 25 shares germ plasm with cucumbers that are grown in the southern United States (L. Baker, personal communication). The resistant cultivar of cucumber has germ plasm that is grown in the northern United States. We are investigating whether greater sensitivity

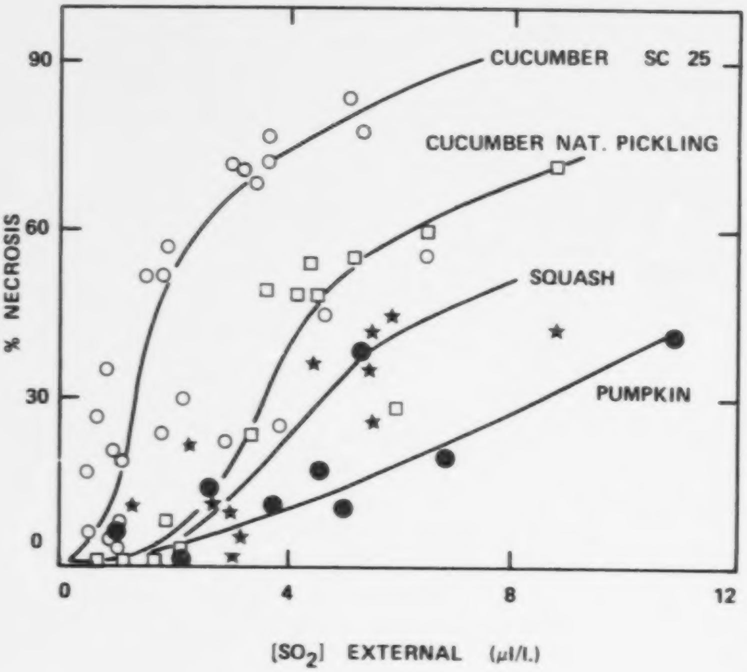

Figure 1. Dependence of injury of four cultivars on concentration of SO_2 in air during fumigation.
Each point is the mean of 4 or 5 plants having a total of about 40 leaves. Each leaf was scored separately. Fumigations were normalized to 1000 minutes.

TABLE 1. CORRELATION OF INJURY FROM SO_2 AND ABSORPTION OF SO_2 IN THE CUCURBITACEAE

I	II	III	IV	V	VI	VII
Cultivar	Mean Exposure µl SO_2 liter^{-1}	Mean Percent Necrosis	Mean Absorption nmoles SO_2 cm^{-2}	Mean Exposure / Mean Percent Necrosis	Mean Absorption / Mean Percent Necrosis	Number of Experiments
Cucumber SC 25	3.6	52.8	342	0.068	6.5	17
National Pickling Cucumber	3.5	32.9	204	0.106	6.2	14
Prolific Straightneck Squash	3.6	21.3	159	0.169	7.5	11
Small Sugar Pumpkin	3.6	17.6	141	0.205	9.5	8

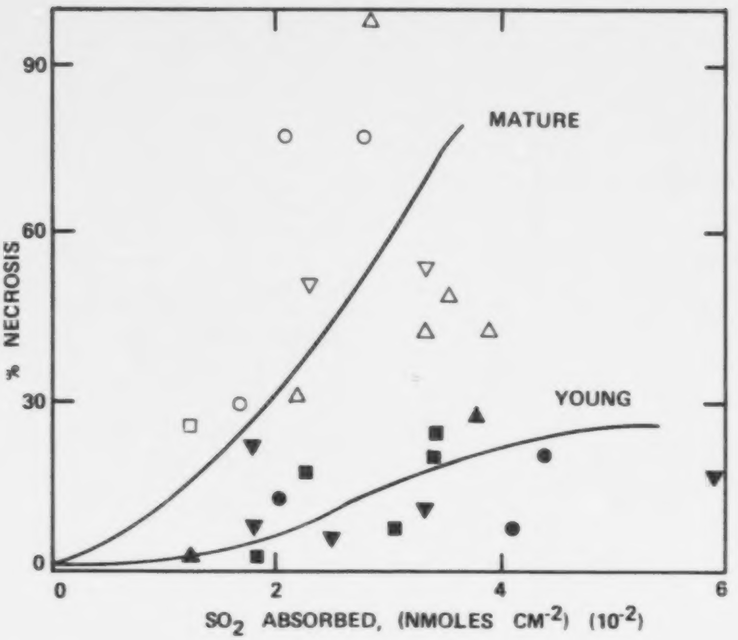

Figure 2. Dependence of injury of young leaves and mature leaves on the amount of SO_2 absorbed. Each point is the mean of 4 or 5 plants from which the upper (open symbols) or lower (filled symbols) 50% of the leaves were removed prior to fumigation. Circles: cucumber SC 25; squares: cucumber National Pickling; pyramids: squash; inverted pyramids: pumpkin.

to SO_2 is a common property of cucumber cultivars developed in the South. We are also determining the pattern of inheritance of this character, to see if the SO_2 resistance character of cultivars developed in the North can be transferred into the Southern cultivars.

Although our concern is with the problem of injury of plants by SO_2, it may be worth pointing out that plants might be useful for removing SO_2 from air. For example, several cucurbit plants in series probably would be sufficient to clean air at 10 L min^{-1}. Could there possibly be some application of several glass houses in series, containing thousands of plants with a high degree of biochemical resistance rather than uptake resistance, through which thousands of liters of air, containing SO_2 diluted to a subtoxic level, could be passed per minute and thereby cleansed of SO_2? It seems only fair that, since there is now reason to suspect that plants may contribute appreciable amounts of sulfur to the air as H_2S, they should be called upon to help remove some sulfur in the form of SO_2.

CONCLUSIONS

In cultivars of the Cucurbitaceae, and probably in most other flowering plants, there are at least two mechanisms by which resistance to acute injury from SO_2 can be achieved. The first mechanism is genetically or phylogenetically determined resistance to absorption of SO_2. The second mechanism is developmentally controlled, and enables young leaves to absorb SO_2 without injury. It is presumed to be a consequence of a ubiquitous but unknown biochemical difference between young and mature leaves.

The emission of H_2S from plants exposed to SO_2 (bisulfite) is not causally related to injury. Under certain conditions, plants fed their normal sulfur source, sulfate, will also emit H_2S, at rates sufficiently high to raise the possibility that plants may contribute appreciably to atmospheric sulfur.

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METHODS DEVELOPMENT, FIELD ASSESSMENT, AND TROPHIC RELATIONSHIPS OF BIOLOGICAL COMMUNITIES IN FRESHWATER ECOSYSTEMS

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INTRODUCTION

A basic factor in the economic growth of the Nation has been the availability of an abundant supply of energy. Recently, however, usable energy resources have become more and more limited. This decrease in supply has led to a national program aimed at developing new, more efficient energy systems. In developing these systems, an equally high priority has been placed on identifying, evaluating, and predicting the environmental consequences of energy-related technologies. Legislation pertaining to these concerns includes the Federal Water Pollution Control Act, the Clean Air Act, and legislation on strip mining.

As part of the Federal interagency energy research program, the Water Quality and Ecology Branch, Division of Environmental Planning, TVA, is participating in the environmental effects research program being coordinated by the Office of Energy, Minerals, and Industry of the Environmental Protection Agency (EPA). The research discussed in this paper deals with five topics that emphasize the environmental impacts of energy-related technologies on the aquatic environment. These projects have been grouped according to five areas of concern: (1) thermal effects, (2) strip mining, (3) biomonitoring of energy technologies, (4) evaluation of power plant intake structures to minimize entrainment of biological organisms, and (5) development of information systems.

THERMAL EFFECTS

To determine the impact of thermal discharges on important fish food organisms, selected studies were conducted at the Johnsonville Steam Plant in western Tennessee. Monthly temperature profiles indicated that the thermal plume from this plant extended from the surface of the discharge channel to the bottom during most of the winter months. As a result, the immature stages of the mayfly Hexagenia bilineata (Say) and the midges (Chironomidae) inhabiting the discharge channel sediment were exposed to a changing thermal environment. The higher thermal regime [temperature differentials (ΔTs) up to 6.5°C] appeared to have increased the growth rate of H. bilineata nymphs in the discharge channel, as compared with the growth rate of nymphs at the ambient station (Figure 1).

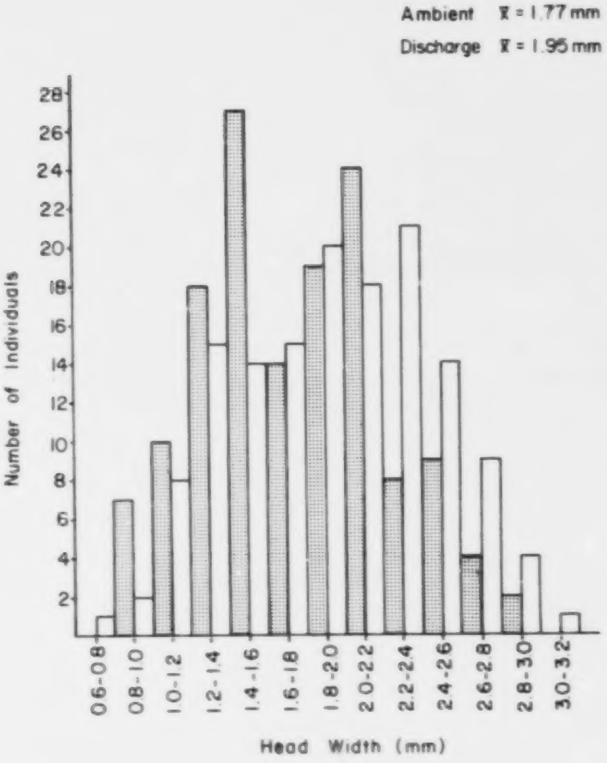

Figure 1. Size of Hexagenia bilineata nymphs in control (strippled bars) and discharge (clear bars) stations at Johnsonville Steam Plant, March 31, 1977.

In testing the tolerance of H. bilineata and the midge Coelotanypus tricolor (Loew) to thermal shock, immatures were exposed for three hours to a series of ΔTs (10, 20, and 30°C) after acclimation for one week at 15°C. No significant mortality occurred at a ΔT of 10 or 20°C, but 100 percent mortality resulted at a ΔT of 30°C (Figure 2). These results indicate that immatures of these species can survive a sudden rise in temperature similar to that experienced at Johnsonville Steam Plant (ΔT of 6.5°C).

Another important stage in the insect life cycle, the egg, may also be exposed to thermal stress. Therefore, baseline data on egg hatching were obtained to determine the range of temperatures at which hatching would occur and the optimal temperature for hatching. Eggs of H. bilineata hatched in 12 to 13 days at temperatures between 25 and 30°C, which was considered the optimal range. These data are now being used to design experiments on embryonic tolerance to thermal shock.

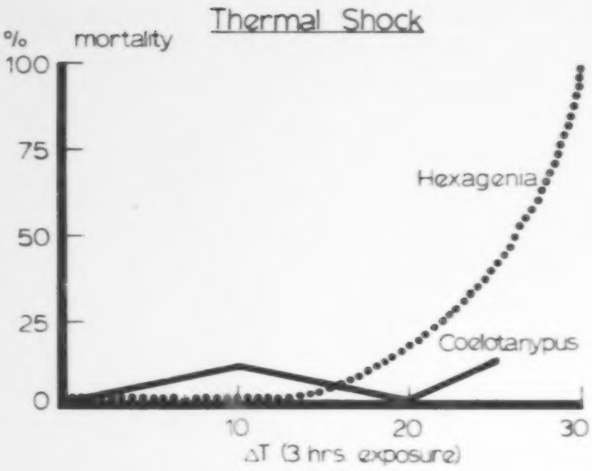

Figure 2. Mortality in Hexagenia and Coelotanypus when exposed to various direct thermal shocks.

STRIP MINING

As noted in the President's comprehensive energy plan, coal is the principal energy resource to be exploited in the United States in the foreseeable future. Historically, coal has been extracted by deep mining, but increased demand has fostered more and more strip or open-pit mining. In Appalachia alone, over 65,000 acres of land are mined each year with 8,000 acres of that total occurring in the Tennessee Valley. As a result, more than 1,500,000 acres have been mined or affected by mining operations in the 11-state Appalachian region. Not only are the environmental consequences of uncontrolled strip mining aesthetically unacceptable, but they also disrupt the natural productivity and assimilative capacity of the terrestrial-aquatic ecosystem.

With the increased emphasis on strip mining, a research project has been identified in conjunction with the interagency energy program to develop a model that can be used for planning development of surface mines. The model considers the (1) potential effect of various techniques for reclamation on the quality and quantity of local streams, (2) biological impacts of surface mining, and (3) cumulative effects of pollutants from multiple mines.

A schematic of the model, which is compartmentalized to simplify modification and improvement of each major component, is presented in Figure 3. The top three blocks of the diagram illustrate the types of site information being collected for the models.

First-order models of stream hydrology and water quality are being used to predict information on transport of water quality constituents based on the characteristics of the watershed, techniques employed, and reclamation measures used. These nonpoint source models can also be used to predict the response from larger mined watersheds and unmined areas. The quantity and quality of streamflow generated by the first-order stream models will be used to provide input to the aquatic biota model.

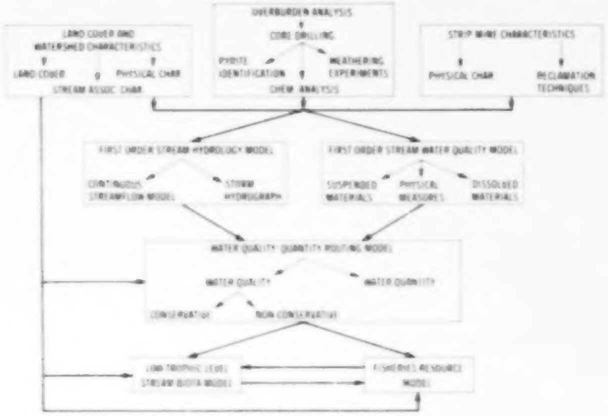
LAND COVER AND WATERSHED CHARACTERISTICS
LAND COVER
PHYSICAL CHAR
STREAM ASSOC CHAR
OVERBURDEN ANALYSIS
CORE DRILLING
PYRITE IDENTIFICATION
WEATHERING EXPERIMENTS
CHEM ANALYSIS
STRIP MINE CHARACTERISTICS
PHYSICAL CHAR
RECLAMATION TECHNIQUES
FIRST ORDER STREAM HYDROLOGY MODEL
CONTINUOUS STREAMFLOW MODEL
STORM HYDROGRAPH
FIRST ORDER STREAM WATER QUALITY MODEL
SUSPENDED MATERIALS
PHYSICAL MEASURES
DISSOLVED MATERIALS
WATER QUALITY QUANTITY ROUTING MODEL
WATER QUALITY
WATER QUANTITY
CONSERVATIVE
NON CONSERVATIVE
LOW TROPHIC LEVEL STREAM BIOTA MODEL
FISHERIES RESOURCE MODEL

Figure 3. Schematic diagram of model components.

A flow diagram of the generalized biological model, in which three different levels of interaction are noted, is presented in Figure 4. The source level refers to those components that serve as food. The reactors consist of two basic modules, a zoomacrobenthic and a fisheries module, which are indicated by the two groups in the diagram. The groups are identified according to their functional role in the stream ecosystem, thereby making it possible to use this model for other systems. The lowest level of interaction is the sink, which refers to those resources lost from the stream through insect emergence, passive losses, or stream drift.

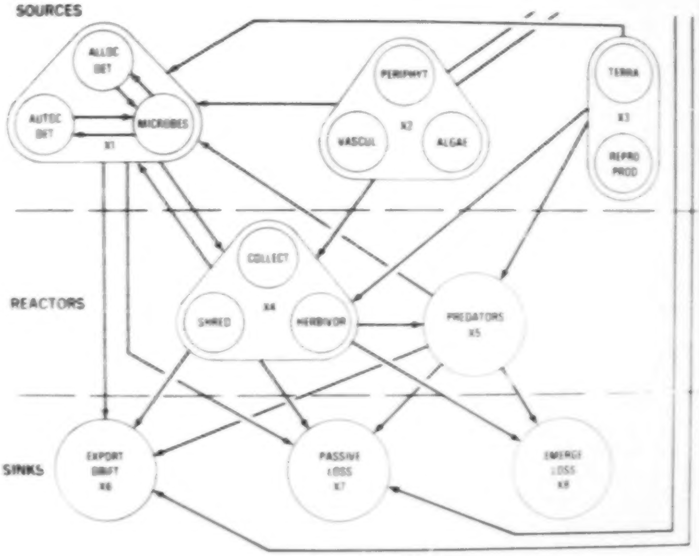
SOURCES
ALLOC DET
AUTOC DET
MICROBES
X1
PERIPHYT
VASCUL
ALGAE
X2
TERRA
X3
REPRO PROD
REACTORS
COLLECT
SHRED
X4
HERBIVOR
PREDATORS X5
SINKS
EXPORT DRIFT X6
PASSIVE LOSS X7
EMERGE LOSS X8

Figure 4. Generalized biological model, Jamestown area streams.

In the field work associated with this project, twelve study sites in east-central Tennessee have been selected for developing baseline information. Six of the sites are in contour-mined areas, and the other six are in area-mined regions. The land cover and watershed characteristics of each site have been documented through aerial photography, topographic mapping, and site inspections.

Because water quality is influenced by the characteristics of the soil covering the coal, overburden samples are being analyzed for neutralization potential, acid production potential, and other direct measures of pyrite reactivity. These samples are also being subjected to laboratory leaching studies to determine leachable acidity, alkalinity, and specific metals.

Two models developed by TVA - a daily streamflow model and a storm hydrograph model - have been applied using data collected at other sites and compared with observed data. Significant progress has also been made toward modeling concentrations of suspended solids in mine drainage by using a modification of the universal soil loss equation. A temperature model has also been calibrated for use on sites in the Cumberland Plateau.

A separate, unique project also associated with strip mining deals with the production of arthropod pests and vectors in pools formed by strip mining and is being coordinated with TVA's vector control program. Monthly biological samples have been collected from nine study ponds (selected on the basis of age) and likely sites for oviposition near the ponds. Seven species of mosquitoes, five of which actively feed on man, have been found. Anopheles punctipennis and Culex erraticus have been the most prevalent species, and Anopheles quadrimaculatus, the malaria vector, was found in significant numbers.

In addition to mosquito larvae, a total of 72 other taxa were collected. Larvae of the midge family Chironomidae (Genus Procladius) were discovered with deformed mouthparts (Figures 5 and 6). Preliminary data indicate that the age of the strip mine ponds may be an important factor in the incidence of the mouthpart anomalies. A study to determine the causes of the abnormalities has been initiated by an agreement between EPA and TVA.

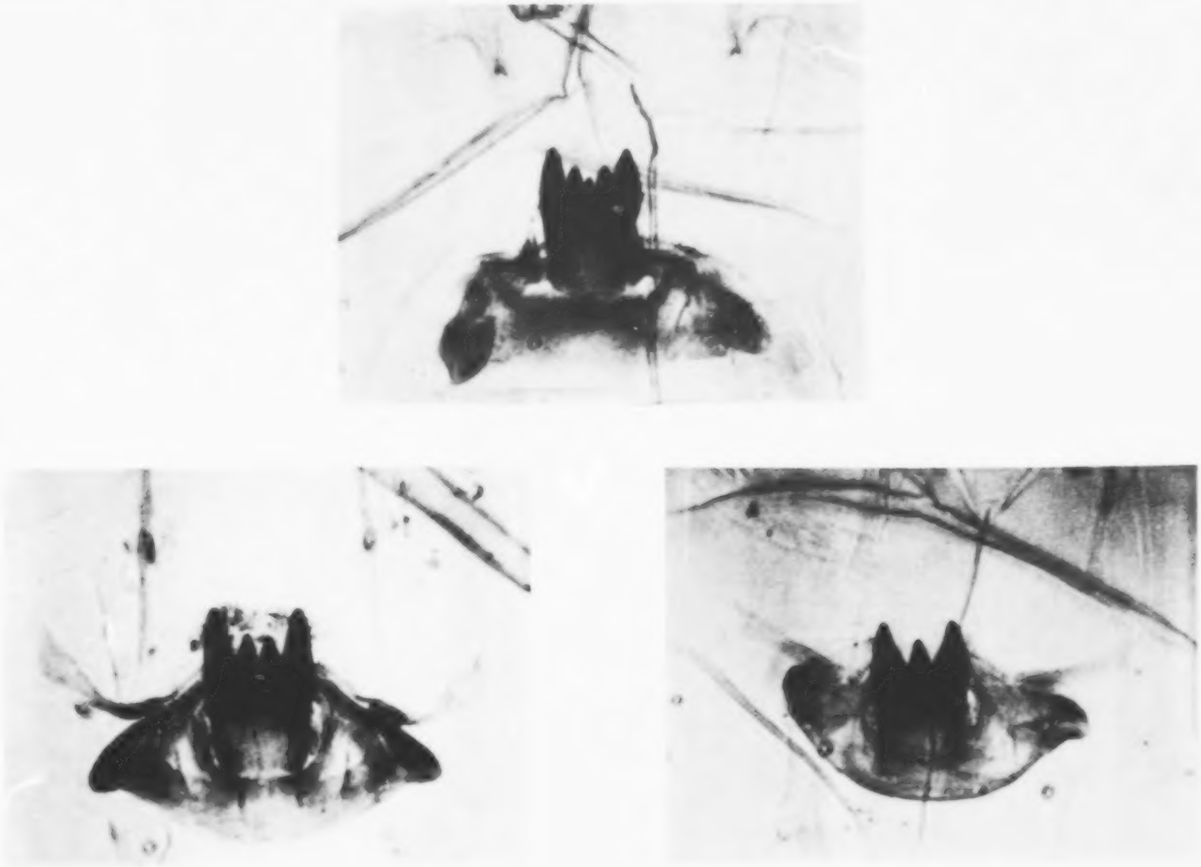

Figure 5. The typical number and configuration of labial teeth for the midge larvae Procladius sp.

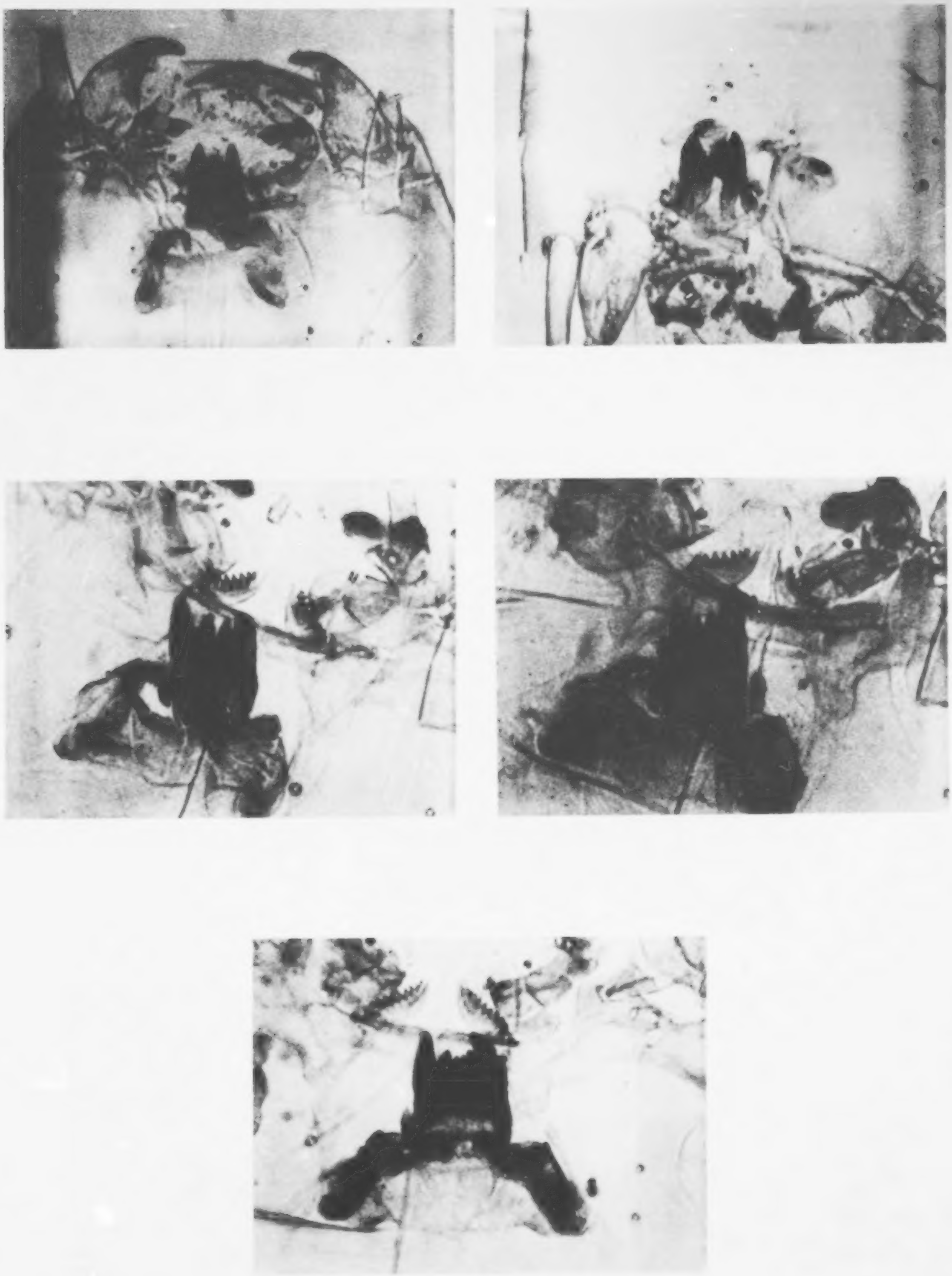

Figure 6. Abnormal configuration of labial teeth for the midge larvae Procladius sp.

Although most of the research tasks described thus far have dealt with energy extraction, the environmental impacts of by-products from coal combustion and nuclear fission have not been overlooked. Studies of trace metals and radionuclides are being conducted at the Bull Run Steam Plant on the Clinch River and the Browns Ferry Nuclear Plant on the Tennessee River. Mussels are being used as indicators of bioaccumulation because they have relatively long life cycles (up to 30 years or more), feed on suspended particulate matter, and live in one general area throughout their life.

Because there are several potential avenues for contaminant cycling, special analytical procedures have been developed or refined during this first year of study. The techniques that have been identified and are subsequently being evaluated are atomic absorption, anodic stripping voltammetry, and atomic emission spectroscopy. These procedures are now helping establish concentrations of heavy metals in the extrapallial fluids and tissues of freshwater mussels from both natural undisturbed areas and power plant sites.

EVALUATION OF POWER PLANT INTAKE STRUCTURES TO MINIMIZE ENTRAINMENT OF BIOLOGICAL ORGANISMS

Power plants have a variety of influences on a body of water, depending on such factors as the type of cooling system used, quantity of river flow diverted for cooling, temperature rise above ambient, proximity to other plants, and design of intake and discharge structures. The objective of this task is to determine whether the specific design, siting, and operation of intake structures can mitigate the effects on zooplankton by reducing the numbers of organisms entrained in the condenser cooling water systems of steam-electric power stations.

The zooplankton are an assemblage of microscopic animals suspended in the water column that are capable of swimming short distances and avoiding weak currents. The freshwater zooplankton are dominated by planktonic species of three major groups: the Rotifera and two subclasses of the Crustacea, the Cladocera and Copepoda. Generally, zooplankton function as primary consumers. This energy transfer is important in the aquatic food web because it makes the solar energy captured by the phytoplankton available to the higher trophic levels--larger invertebrates, small fish, large fish, and other vertebrates. Although few adult fish feed directly on plankton, most depend directly on plankton as food while they are in the larval and postlarval stages.

Figure 7 shows four types of intakes to be evaluated. Intake "A" has a skimmer wall, long intake canal, and relatively shallow depth (less than 20 ft). Intake "B" is similar to "A" but is deeper (greater than 20 ft). Intake "C" has a short intake canal and no skimmer wall, and intake "D" is situated directly on the shoreline. These types of intakes exist at various TVA power plants.

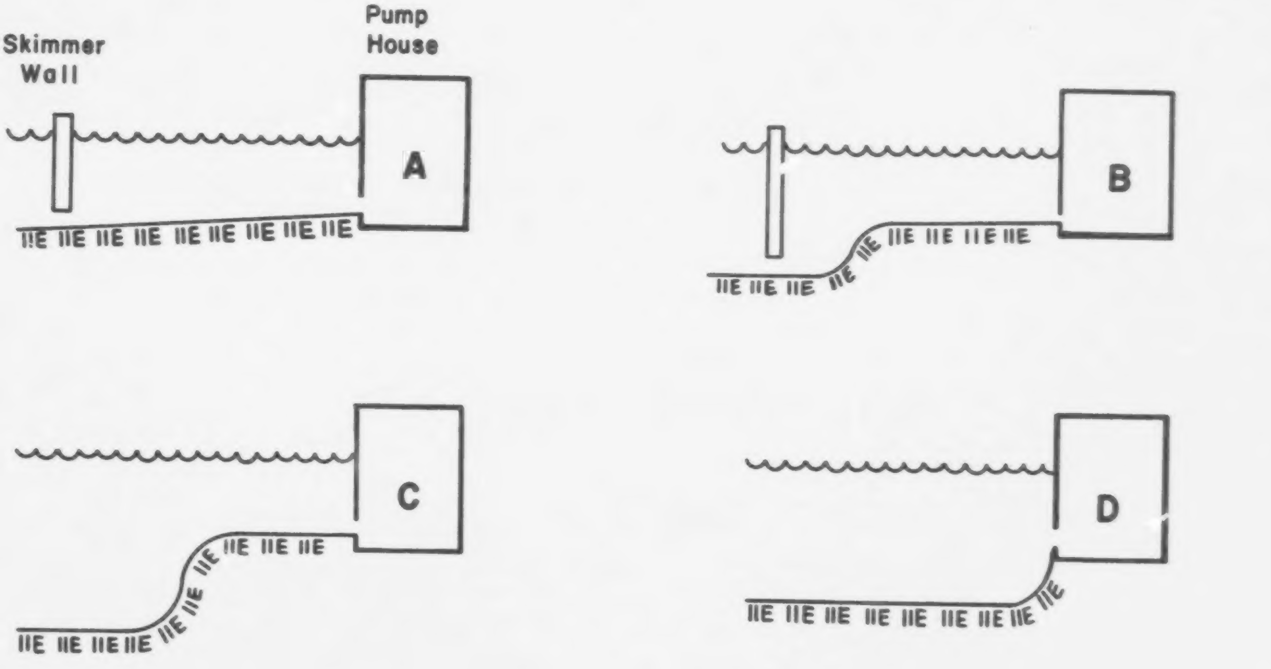

Figure 7. Types of intakes at various TVA power plants.

During the first year of study, two different situations were examined--one involving an intake with a deep skimmer wall (intake "B") and the other involving a bend of a river. Results for the studies at the skimmer wall indicate that total numbers of zooplankton were 69 to 72 percent less than those from comparable samples collected outside the skimmer wall. These numbers were found to depend directly on the numerically dominant zooplankton group. Rotifera, found during the study. The Calanoida, like the Rotifera, were less numerous inside the skimmer wall (intake canal) than at stations outside the skimmer wall. However, the Cladocera and Cyclopoida were more numerous (up to 91 and 506 percent, respectively) in the intake canal than at comparable depths in the reservoir. These results indicate that the Rotifera and Calanoida predominated in the upper strata of the water column, whereas the Cladocera and Cyclopoida were more numerous in the deeper strata. Consequently, the latter two groups were selectively pulled under the deep skimmer wall into the intake canal.

For studies at the river bend, two different sites were selected on the basis of their flow velocities. Distribution patterns for the site with very little current showed the inner and outer banks to have similar numbers or the outer bank to have slightly greater numbers, depending on the zooplankton group. The site with high water velocities showed the numbers of total zooplankton, Rotifera, and Calanoida to be similar along the inner and outer banks, but the Cladocera and Cyclopoida were 50 to 100 percent more numerous along the outer bank.

DEVELOPMENT OF INFORMATION SYSTEMS

When the Water Quality and Ecology Branch initiated the energy effects research program, one project was identified for developing the capability to measure and predict the impact of energy technologies on important biotic assemblages. To accomplish this task, the first priority was to develop a computerized information system to accommodate biological data. The general design criteria for the system were that it must be (1) compatible with EPA's STORET/BIO-STORET systems, (2) inexpensive and user oriented, (3) adaptable for use with both routine monitoring and research programs, and (4) able to perform a variety of analytical procedures.

Using these criteria, we combined three systems to form one data management/information system (DM/IS). A hierarchical flow diagram showing the interrelationship between the systems is presented in Figure 8. In its present stage of development, the DM/IS uses the statistical analysis system (Barr et al. 1976) for its routine day-to-day operations such as creating and manipulating data sets; printing, sorting, and ranking data; and performing routine statistical procedures. As noted in Figure 8, the DM/IS is also used with other software packages to compute more sophisticated analytical procedures.

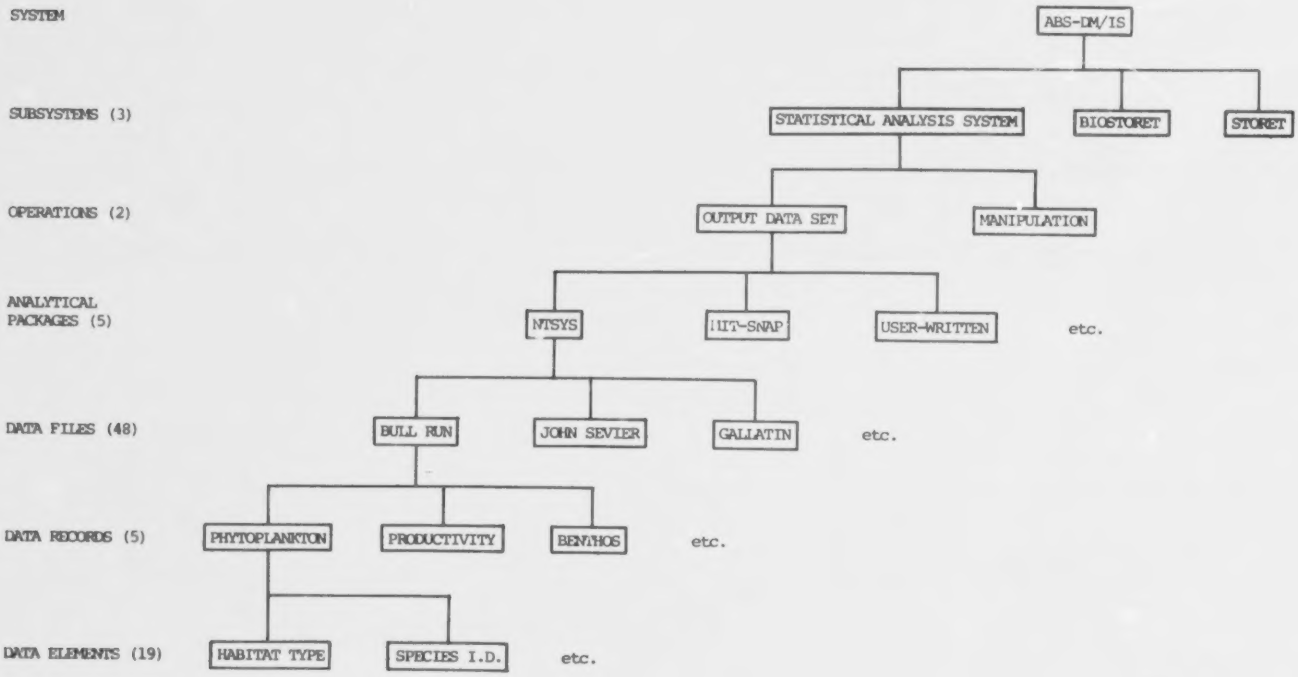

Figure 8. A flow diagram of the data management/information system used by the Tennessee Valley Authority's Water Quality and Ecology Branch.

To store and manipulate the large volume of information collected by TVA, a series of numeric and alphanumeric codes was developed. These codes allowed for (1) easier storage and retrieval of biological data; (2) savings in time and money each time the data were sorted, compiled, and analyzed; and (3) centralization of the data to make writing environmental reports easier. The coding scheme used and subsequently expanded was developed under the direction of Dr. Cornelius Weber, EPA, for use with BIO-STORET, the national data storage and retrieval system for biological data. The classification system consists of seven data fields, which make accommodation of data at any level of taxonomic distinction possible. The maximum number of digits that can be assigned any species is 16, which can be broken down into the following taxonomic groups:

Taxonomic group (data field)	Digits in data field	Numeric values
Phylum or division	2	01-99
Class	2	01-99
Order	2	01-99
Family	2	01-99
Genus	3	001-999
Species	3	001-999
Variety, form, authority	2	00-99
Total	16	

A typical 16-unit species code would be 1701010300100100. In this example, the organism was identified to the taxonomic level of species and the authority specified. When broken down further, the following information can be obtained:

17	Phylum: Annelida
1701	Class: Oligochaeta
170101	Order: Plesiopora
17010103	Family: Aeolosomatidae
17010103001	Genus: Aeolosoma
17010103001001	Species: hemprichi
1701010300100100	Authority: Ehrenberg

This hierarchical code has made possible the accommodation of biological data at any level of taxonomic distinction while limiting the space requirements to just 16 units. Another feature that has been built into the DM/IS is quality control. For example, if an erroneous or unique data entry is found, the computer prints out one of the following error messages:

Invalid scientific name - contact J. Crossman, Water Quality and Ecology Branch, Ext. 727.

Geographic distribution does not include the Tennessee Valley.
Geographic distribution does not include the southeastern United States.
Geographic distribution does not include North America.
Listed on rare and endangered species list.
Scientific name has been changed to _________

With completion of the initial phase of the DM/IS, emphasis has been placed on exploratory data analysis and the selection of representative important species for culturing. One analytical procedure being tested is the clustering subroutine contained in the numerical taxonomy system (NTSYS). Using this subroutine, we have been able to determine the similarity of selected river sites on the basis of the biotic assemblages present and to identify unique biological communities or species assemblages.

Another method being tested is an ordination technique called nonmetric multidimensional scaling, which allows us to examine the information in a scatter diagram without first having to assume that the data form clusters. Ordination, therefore, served as both an alternative to cluster analysis and as a check to determine whether species actually form distinct assemblages or whether the assemblages are the result of the clustering procedure.

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ECOSYSTEM CHARACTERIZATION – AN APPROACH TO COASTAL NATURAL RESOURCE PLANNING AND MANAGEMENT

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INTRODUCTION

We are at a crossroads in our technological evolution. Having successfully passed through stages of empirical and scientific approaches to progress, we are at the threshold of a new age which will mould our future through the integration of knowledge acquired in many diverse disciplines. Problems we face today are so complex and wide-ranging that solutions require a holistic approach. The principal strands of the new web of understanding are supported by three disciplines: technology, sociology, and bio/ecology. Together they comprise our environment (Figure 1).

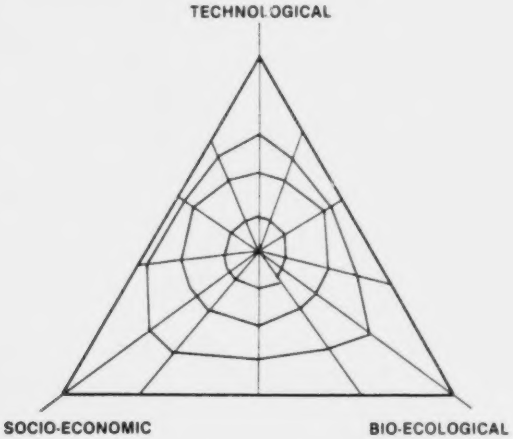

Figure 1. Information web required for comprehensive natural resource management.

Bio/ecological components alone can range in scope from systems as small as the gene to those as large as the biosphere. This paper suggests a midlevel, ecosystem approach to synthesizing ecological information which will provide immediate benefits to researchers, decision-makers, and planners and serve as a module readily adaptable to future holistic systems.

Coastal ecosystems offer a particularly complex challenge requiring the integration of information dealing with air, land, marine, estuarine, and fresh water systems. Concentrated human populations and diverse development activities have likewise focused on these continental fringes. It is against this background that the ecosystem characterization process described in this paper has been developed.

Definition and Purpose

The concept of ecosystem characterization is not very profound nor complicated. A useful definition is a description of the important components and processes comprising an ecosystem and an understanding of their important functional relationships. Strong emphasis is placed on systems understanding through structured integration of information from the diverse physical and biological sciences. Key elements of the concept are outlined below:

Ecosystem Characterization - Definition.

- Related to a specific ecosystem
- Provides a basic perspective of the state of knowledge for the given system
- Provides a description of the important ecosystem components and functional processes
- Provides a mechanism for ecosystems understanding through the integration of components and functional processes.

Ecosystem Characterization - Purposes.

Provide an understanding of ecosystems to assist in:

- Integration of complex ecological information
- Identification of information deficiencies
- Establishing research priorities
- Comprehensive Planning
- Assessment and prediction of environmental impacts
- Developing mitigation procedures and alternatives for minimizing environmental impacts.

APPROACH

Ecosystem characterization is guided by a structured approach to the synthesis of diverse environmental information. To be effective, each step of the process must be followed sequentially as outlined in Figure 2.

Ecosystem Description and Boundaries

The ecosystem, as a basic unit for describing natural systems, has come to be a widely accepted term to scientists as well as resource managers. Inherent in the concept are:

- Functional relationships between organisms and their physical environment.
- Composed of plant and animal assemblages which are relatively homogenous response units often referred to as communities.
- Ecosystems are open systems through which energy and matter are continually exchanged.

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This latter principle has made it difficult to delineate the precise boundaries of a given system. (Evans, F.C. 1956. Science 123:1127-1128).

Coastal ecosystems are more easily envisioned than described. The rocky coast of Maine, the extensive low lying wetlands and bayous of Louisiana, the mangrove/coral systems of tropical Florida and the barrier island coast of Texas can each be conceived as unique ecosystems in spite of the fact that they are open to the ocean, inland riverine and terrestrial systems, and to adjacent coastal systems.

Forces moulding the structure of the system include meteorological phenomena, wave energy, sediment transport, and long-term processes of subsidence and climatic and geologic change. These physical processes result in the establishment of the environment and substratum upon which biological communities develop. In turn, the communities influence the continued evolution of the system.

The Chenier Plain ecosystem, for example, is considered a transition zone between the active Mississippi River delta to the East and the relatively stable barrier island system to the West. Fluctuations of sediment availability from the Mississippi River over the past 5,000 years have resulted in the accretion of a vast coastal system composed of emergent wetlands, lakes, ponds, estuaries, tidal channels, and slightly elevated stranded beach ridges. Like similar extensive estuaries, the Chenier Plain owes its existence to the rel-

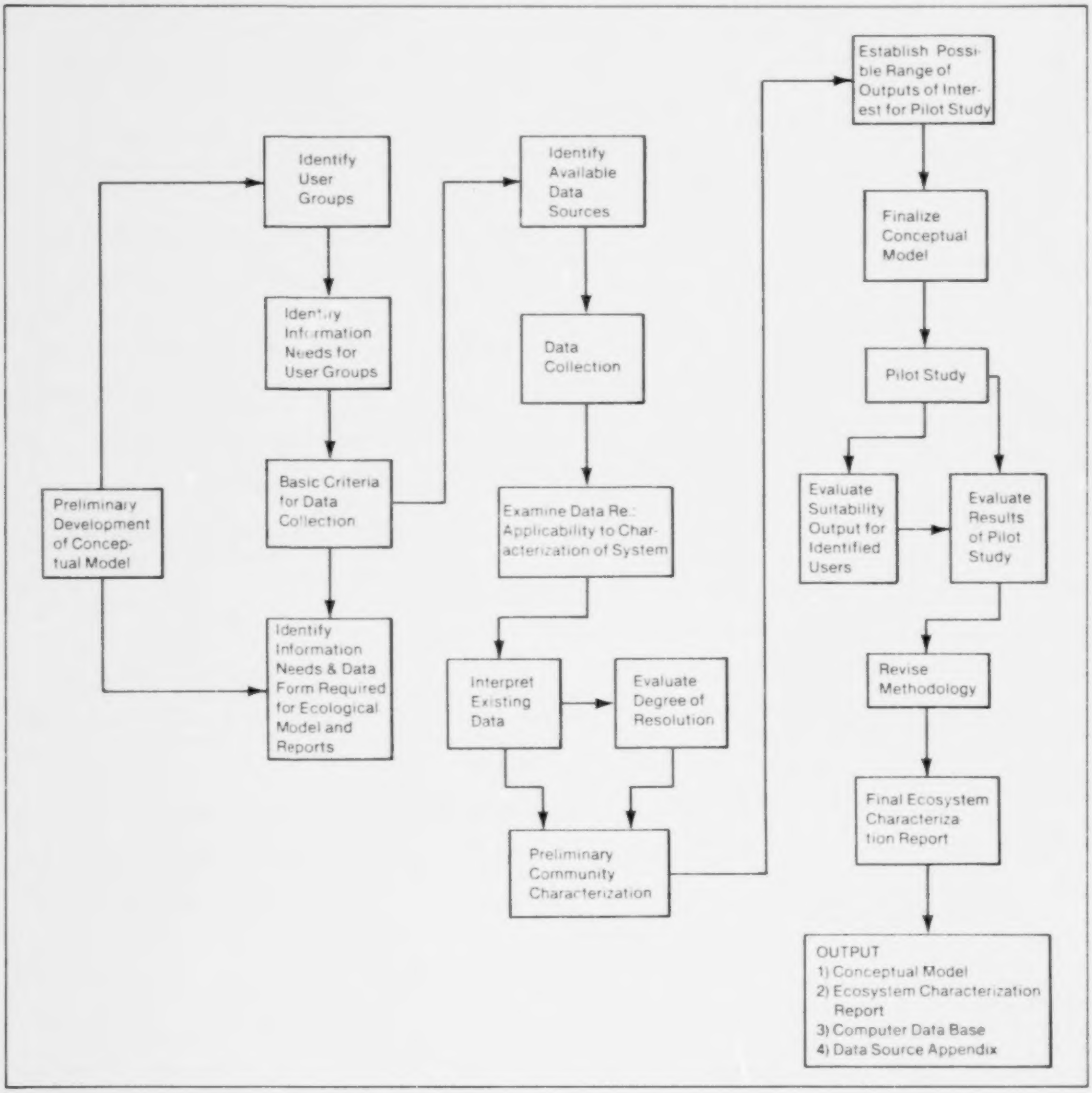
Preliminary Development of Conceptual Model
Identify User Groups
Identify Information Needs for User Groups
Basic Criteria for Data Collection
Identify Information Needs & Data Form Required for Ecological Model and Reports
Identify Available Data Sources
Data Collection
Examine Data Re.: Applicability to Characterization of System
Interpret Existing Data
Evaluate Degree of Resolution
Preliminary Community Characterization
Establish Possible Range of Outputs of Interest for Pilot Study
Finalize Conceptual Model
Pilot Study
Evaluate Suitability Output for Identified Users
Evaluate Results of Pilot Study
Revise Methodology
Final Ecosystem Characterization Report
OUTPUT
1) Conceptual Model
2) Ecosystem Characterization Report
3) Computer Data Base
4) Data Source Appendix

Figure 2. Ecosystem characterization approach.

ative stability of sea level over the past several millennia and the abundant sediment supply of a major river. Ecosystem boundaries, although defendable, have been somewhat arbitrarily established and reflect the functional differences between adjacent systems.

With this natural background plus a 30 year history of onshore and offshore oil and gas and other development activities, the Chenier Plain provides an ideal setting for piloting the implementation of the ecosystem characterization concept.

Conceptual Ecosystem Model

Once the boundaries of the system have been established, the next step is the development of a conceptual ecosystem model. The model provides the framework for identifying important natural resource components of the system and the functional processes which affect their survival and productivity.

Modeling the Chenier Plain involves a three level analysis of the system. A broad regional model considers the entire ecosystem emphasizing geomorphology and the geologic processes responsible for the origin and long term system changes. Most natural changes at the ecosystem level occur on the order of thousands of years and it is difficult to incorporate the information into planning and impact analysis procedures. The framework is useful, however, for providing a proper perspective to the other components of the system (Figure 3).

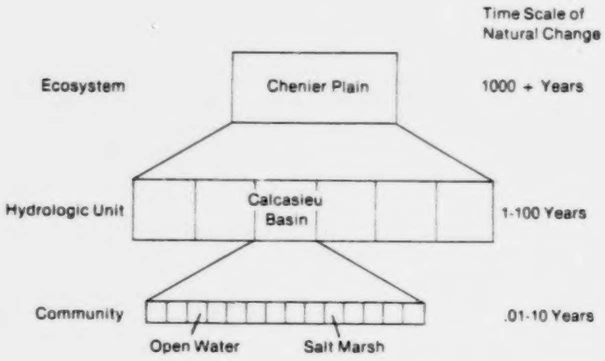

Figure 3. Stratified organization of conceptual model of chenier plain ecosystem.

The Chenier Plain ecosystem was subdivided and modeled as six subsystems generally representing different drainage basins or hydrologic units. Hydrologic processes dominate basin function and provide a mechanism for integrating basin components. Natural change is on the order of one to several hundred years, a useful scale for planning and impact analysis.

The third level of resolution is a relatively homogenous unit which variously might be termed communities, associations or habitats. Basins, therefore, emerge as spatially heterogeneous areas composed of a number of interacting communities. At the community level change is constant, seasons come and go, plants and animals live and die and man's impact on the environment is most apparent. It is the community or habitat which is altered by dredging, polluted by oil spills or drained for agricultural, urban or industrial development. Since this level results in the most obvious environmental changes, it is the level that has received most of the attention regarding impact analyses. The challenge of the conceptual model is to identify functional relationships between communities which would permit planning and cumulative impact analysis at the basin level.

Modeling diagrams, interaction matrices and narrative accounts are used to highlight important resource components and processes. A "blueprint" for guiding future data collection synthesis and analysis is then prepared as the final stage of the conceptual model.

Information synthesis and analysis

Once the priorities for ecosystem information needs have been established by the conceptual model, the arduous task of data compilation is initiated. Fundamental to ecosystem characterization is the structured accumulation of all existing information identified by the model as being significant. This phase of the process requires the identification of all published material as well as information stored in files, unpublished reports, and in the heads of individuals familiar with the area's ecology.

The conceptual model also assists in making full use of the available information by establishing the boundaries of transferability. Site-specific information from a single estuary, for example, might be applicable to other estuaries within the same hydrologic unit but data from outside the system would have to be carefully screened to establish relevance. In this way maximum use is made of all available information.

Data is accumulated into two reference systems: literature cited and a data source appendix. Material referenced in the literature cited section would be available in major libraries within the geographic area of the characterization study. Standard sources (books, journals, monographs, theses and dissertations, etc.) would be included in the literature cited. The data source appendix contains information compiled from unpublished sources which are generally unavailable to users.

The products of the data synthesis and analysis phase include:

- o The Ecosystem Characterization Report describing the system and highlighting important natural resources and the processes which affect their distribution and productivity. The report is designed primarily to provide an understanding of the system through sufficient narratives, graphs, maps, tables, and illustrations. It does not represent the primary data source although a comprehensive literature cited is part of the report.

- Data Source Appendix forms the major data base developed during the course of the study. This massive document contains tables, graphs, maps, and associated narratives. Together with the published literature, it represents a primary source of information on the environment of the ecosystem. Steps are being taken to develop a standardized automated system to locate, access and transfer the information.

Scheduling

An important aspect of the characterization approach to planning environmental study programs is that useful information can be developed early in the program. Approximately 20 months are required to complete the process. The first activity is a general survey of user needs focusing on federal and state agency interests followed within 3 months by a draft of the conceptual model. A pilot characterization area is selected and an intensive data acquisition phase is undertaken. The purpose of the pilot, usually a basin within the ecosystem, is to develop and present the data format which will be used in the final characterization report and data source appendix. The user group will have the opportunity to review the pilot six months after work begins, providing ample time to incorporate necessary changes in the final reports. Once the format and content of the pilot have been established, the ecosystem characterization can then proceed rapidly to completion.

USER RELATIONSHIPS

The test of an information system is its value when applied to solving real life problems. To effectively meet user needs their guidance must be sought and incorporated into the planning and development of all phases of the process.

Ecosystem characterization will not provide solutions to all environmental problems arising in the coastal zone. However, it does provide a base of ecological information which will have application to most situations. Activities in the coastal zone range from comprehensive planning, requiring a broad base of information, to site-specific disturbances. To meet these needs, the information base must contain general information highlighting the resources and processes comprising the system as well as specific information on the distribution of fish, wildlife and their essential habitats. The stratified approach presented in the Chenier Plain conceptual model describes a mechanism for structuring information which will address this broad range of needs.

Program specific information is required in addition to the ecosystems data. Figure 4 is a schematic depicting some of the action programs which could use the ecosystem data base. In each case supplemental information must also be available. Agencies responsible for managing action programs usually have resources available to develop program specific information. The outer continental shelf leasing program, for example, is managed by the Bureau of Land Management. As part of the program, the bureau has underway environmental studies to assess the long term impacts of OCS development and to minimize detrimental environmental impacts. Specific kinds of information are being developed in the lease areas to meet the needs of the leasing program. A broad base of ecological data could complement the OCS environmental studies program and assist in the preparation of resource assessments, impact statements and in determining the data requirements of the environmental studies program.

The Fish and Wildlife Service, as mandated under the Fish and Wildlife Coordination Act of 1958 and the Water Pollution Control Act of 1972, has responsibility for the review of applications to permit development and discharge activities in the wetlands and aquatic systems of the United States. Decisions to issue permits is the responsibility of the U.S. Army Corps of Engineers or the Environmental Protection Agency. Dredging and other wetland alterations in the coastal zone may be very site-specific and result in localized change. Information required to adequately assess the impacts of such activities differs substantially from that required for OCS leasing. Ecosystem characterizations, however, could provide information on the distribution and value of wetlands and fish and wildlife resources in the vicinity of the proposed development. Much of the basic site-specific information will be contained in the data source appendix. Furthermore, the ecosystem characterization report would assist in assessing impacts on the important natural functional processes of the system, e.g., alteration of salinities and currents, effects on primary and secondary productivity, sediment transport processes, etc. Information regarding the effects and mitigation procedures specifically associated with dredging must be provided from supplemental sources such as the U.S. Army Corps of Engineers Dredge Material Research Program.

The ecosystems characterization should be regarded as one of a number of tools required to protect and manage living resources. To be effective, other more specialized tools will also be required. It is important that users recognize the tools available to them and the purpose for which they were designed.

PROJECT STATUS

To date four coastal ecosystems are being characterized using the approach described. The Chenier Plain study of southwestern Louisiana and Texas was initiated in April 1976 and is scheduled for completion in July 1977. The other three systems were started in February 1977. They include the coasts of South Carolina/Georgia, the rocky coast of Maine and the Pacific coast from Cape Mendocino, California to Cape Flattery, Washington. Two studies are due for completion in the fall of 1978 and one in February 1979. Funding has been provided through the Federal Interagency Energy/

Environment Research and Development Program administered by the Environmental Protection Agency. The Fish and Wildlife Service has been responsible for the design and management of the characterization contracts. There are approximately 15 coastal ecosystems fringing the 48 contiguous States. The FIE/ER&D program has provided a mechanism to rapidly advance our understanding of a significant portion of our coastal zone and it is hoped that the techniques developed in this program will have broad application by other agencies to other areas.

CONCLUSION

Decisions facing natural resource management become increasingly complex as knowledge advances and interactions are better understood. Improved methods of data integration will become more essential to the application of existing information. Until holistic systems analysis becomes more effective, we will have to rely on modular components to integrate information. Such modules, especially regarding natural systems, can readily be adapted to more comprehensive programs if properly designed.

The characterization process, as outlined, addresses an important functional unit of the environment--the ecosystem. The approach involves the delineation of the physical boundaries of the system, preparation of a functional conceptual ecosystem model, synthesis and analysis of existing information using the model as a "blueprint", the preparation of an interim pilot characterization report which, after review by the user group, will permit the effective production of the final ecosystem characterization report. During the process most of the relevant information about the system will be brought together in a data source appendix. Guidance throughout the project is provided by a user committee to assure that the information will meet action program needs.

The current energy dilemma may be the first true test of our nation's ability to marshal the diverse knowledge we have accumulated over the past few centuries into a program which assures our survival and strives to maintain cultural standards to which we have become accustomed. Ecosystem characterization can provide an important ecological foundation from which to plan and manage for the future of our natural resources.

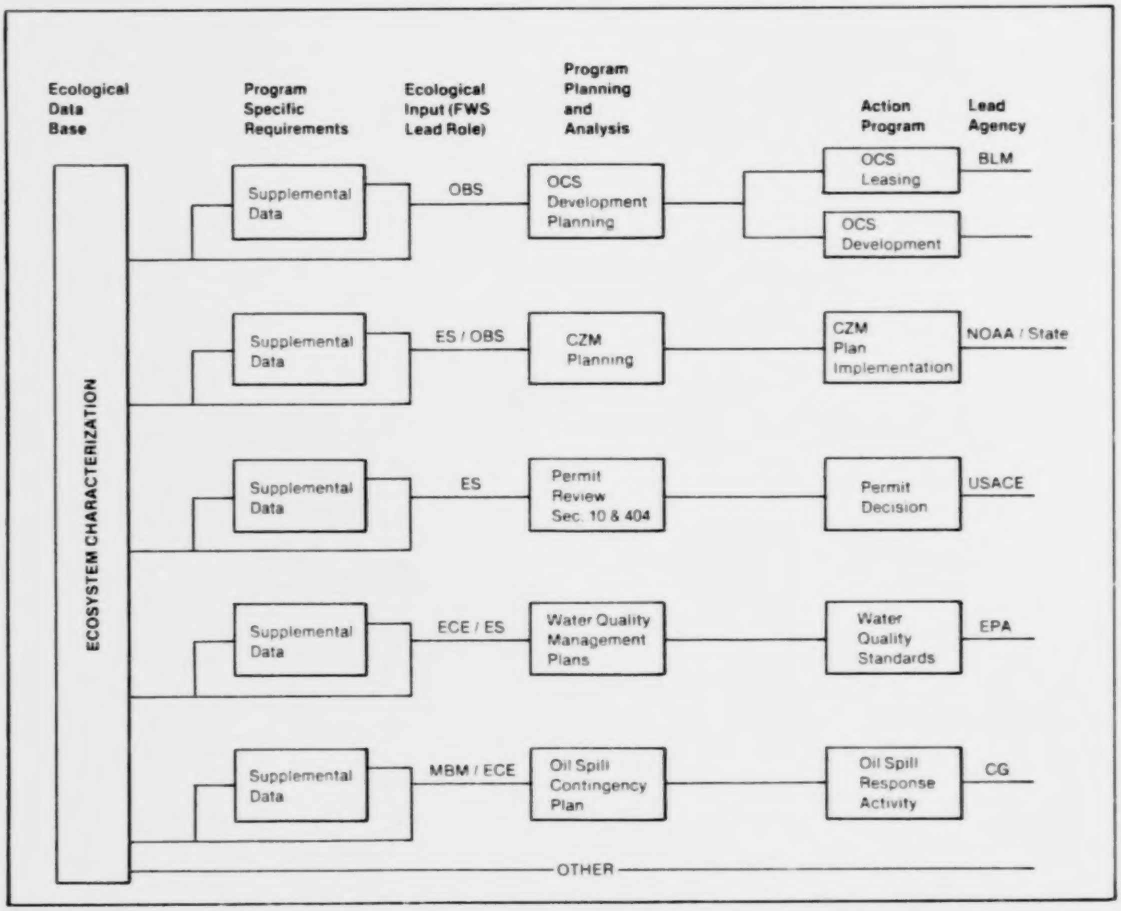
Ecological Data Base
Program Specific Requirements
Ecological Input (FWS Lead Role)
Program Planning and Analysis
Action Program
Lead Agency
ECOSYSTEM CHARACTERIZATION
Supplemental Data
OBS
OCS Development Planning
OCS Leasing
BLM
OCS Development
Supplemental Data
ES / OBS
CZM Planning
CZM Plan Implementation
NOAA / State
Supplemental Data
ES
Permit Review Sec. 10 & 404
Permit Decision
USACE
Supplemental Data
ECE / ES
Water Quality Management Plans
Water Quality Standards
EPA
Supplemental Data
MBM / ECE
Oil Spill Contingency Plan
Oil Spill Response Activity
CG
OTHER

Figure 4. Relationship of ecosystem characterization information to supplemental data requirements and selected Fish and Wildlife Service related action programs in the coastal zone.

ASSESSMENT OF INSTREAM FLOW NEEDS

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INTRODUCTION

An adequate volume of water flowing in streams is essential to the life support systems of many species of fish and wildlife. Adequate supplies of freshwater are also essential for energy development and production. The projected levels of out of stream water use for extraction, conversion, and production of energy sources have signaled the need for careful planning on the part of water resource managers to reduce potential conflicts between these two water uses.

Accurate and timely prediction of the quantity of water which must remain in streams to maintain their dependent natural systems is a prerequisite to improved planning processes which adequately consider fish, wildlife, and other environmental values. At the present time, a credible instream flow field study costs close to $100,000 on the average and requires 1 to 2 or more years to complete. This cost and time frame is generally unacceptable to planners and decisionmakers who need more immediate answers and operate on limited budgets. Since other disciplines have extensive data banks and better methodologies, they are able to make their input to the planning process with information taken "off the shelf" or they can develop the information within the required time frame. This difference between the state-of-the-art of biological assessment and the other disciplines involved in the planning process has lead to frustration for all participants and frequently resulted in the dewatering of streams and the loss of their dependent fishery resources.

To increase the effectiveness of the biological disciplines in water resource planning, the U.S. Fish and Wildlife Service initiated an Instream Flow Program in FY 75 and has been supported in this effort with funding through the Federal Interagency Energy/Environmental Research and Development Program.

The assessment of instream flow needs is a complex and difficult task. It includes not only a diverse range of species, habitats, climatic types and geographic areas, but it also involves the responsibilities and interests of a large number of agencies, organizations, and groups. A recent evaluation of the scope and magnitude of the instream flow problem estimated that $123 million carefully programmed over a 10- to 20-year period would be required to adequately address the problem.

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After considering the magnitude of the problem, the limited resources currently available, and the relatively short time frame within which many energy related decisions will occur, we decided that for the highest probability of success we should concentrate our activity in the area of greatest past experience and largest body of knowledge. We have called this area the "river reach" which refers to stream sections only and excludes other interrelated areas such as upland habitats, wetlands, lakes, reservoirs, flood planes, deltas, and estuaries. Attention can be focused on these areas as additional funds become available and we successfully complete the needs in the river reach area.

The Instream Flow Program has three components: a methodology development component, a data base component, and an institutional component to improve our ability to implement the results of our research. Each component is supportive of the others with feedback among components a major consideration in designing the program. This is part of a larger Fish and Wildlife Service program of research and development focused on the critical problems associated with energy development. Portions of the larger program and the Instream Flow Program are interrelated. This paper is limited to reporting the major accomplishments of the Instream Flow Program to date and indicating its future directions.

TECHNICAL DISCUSSION

Development of Improved Methodologies

As a first step toward improvement of our assessment methods, the Service contracted with Utah State University to conduct a state-of-the-art study. The final report, entitled "Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment," evaluates the adequacy of existing methodologies for determining the necessary stream flows for fish, wildlife, water quality, recreation, aesthetics and other instream uses and recommends needed research and development in each area.

Our overall conclusions were:

1. The many individuals, groups, and agencies involved in predicting altered instream flow effects are seldom aware of the full range of methodologies potentially applicable to their specific situation.

2. Development of most methodologies has taken place in response to a particular problem and in geographic and/or disciplinary isolation.

3. There has been little comparative testing of methodologies.

At the same time the state-of-the-art study was being conducted, surveys were made in the Pacific Northwest, the Rocky Mountains, and California to determine the actual effects on fish and wildlife of altered stream flow characteristics below dams and diversions. In each geographic area, representative samples of habitat types, project purposes, and sponsoring agencies were examined. The results in all three areas indicated the difficulty in prediction, the unequal application of methodologies and procedures available, the frequent failure of the responsible agency to include the features recommended to minimize the adverse effects, and the significantly modified habitats resulting from the projects.

Based on the state-of-the-art study and the surveys of actual field conditions, we concluded that a number of instream flow methodologies were ready for refinement and testing for widespread application, a concerted effort was needed, and a mechanism to share information among practitioners was essential. To provide the necessary focus for the multitude of divergent activities ongoing in this field and to take action based on our conclusions, a Cooperative Instream Flow Services Group (IFG) was established in Ft. Collins, Colorado.

The IFG is truly a multiagency and multidisciplinary team. The Group members were recruited from a variety of agencies at both the state and federal levels, and they brought to the Group expertise in the fields of hydrology, hydraulic engineering, recreation, electronic data processing, water law and decisionmaking, as well as biology. We have been particularly careful in staffing the Group to ensure that a balance was struck between the physical, biological, and legal/institutional aspects of the instream flow problem. Consideration of all aspects is essential to ensure useful and broadly acceptable improved methodologies.

Identification of Basic Data Needs

Concurrent with the consideration of methodology, we began to identify specific potential problems which would need to be addressed if the adverse effects of energy development on freshwater were to be minimized. To maximize the return, we again focused our investigations.

This time we limited our considerations to the Upper Missouri and Upper Colorado River Basins which had been identified as the geographic areas where water for energy development was in shortest supply and most critical.

In the Upper Colorado River Basin, the extreme shortage of unused water and the over allocation of the existing water supplies dominate all other considerations. Direct conflicts are anticipated regardless of when or how energy is developed. In the Upper Missouri, however, consideration of alternative sites and water supplies appears to offer very real opportunities for minimizing adverse environmental effects. In both areas, the lack of basic data needed for planning and evaluation was readily apparent.

Identified top priority research needs and recommendations included the following:

1. The available knowledge on the current range and habitat requirements of endangered and threatened species in both Basins should be compiled and summarized in readily accessible form.

2. A stream classification system should be developed based on flow characteristics, water quality and temperature, aquatic ecotypes, fish populations, and scenic and recreational potential.

3. Fish and wildlife agencies should develop priorities as to what is of critical importance to fish and wildlife, what is important but subject to compromise, and what is unimportant and becomes more active in planning functions which design alternatives.

4. An interdisciplinary research effort should be undertaken, aimed at building systems models for simulating aquatic ecosystems and exploring the sensitivity of certain components (species) of those systems to variations in level and duration of stream flows. Field studies on a variety of types and sizes of streams will be required to test the adequacy of the model.

5. Immediate steps should be taken to improve methods of identifying and mapping areas of special sensitivity in terms of fish and wildlife habitat.

We also found that the problem of identifying potential freshwater effects is compounded by the inability of engineers and planners to predict the most likely future energy development scenario, the mix of future energy sources, or the range of future energy technologies. To adequately respond under these conditions of uncertainty, it is necessary to guard against restricted thinking and confining considerations to watersheds immediately adjacent to energy sources currently proposed for development.

Development of Instream Flow Information System

In order to ensure that the need for identified basic data can be met, an Instream Flow Information System has been developed. Although the information in the system will be primarily from the Western states, it can be easily expanded to cover any desired area of the country and will accommodate all needed stream-related data. At the present time, we are assessing available data bases and supplementing these with studies responding to the needs we have identified. Specifically, the studies include endangered species, stream evaluation, and determination of instream flow needs on critical streams.

The purpose of the Endangered Species Study is to determine the distribution of endangered and threatened species in the Upper Colorado and Upper Missouri River Basins and to determine the stream flow required at specific points for each species' maintenance.

The Stream Evaluation Project is determining the current status of stream fisheries in 15 Western states and evaluating their existing and potential value in fish and wildlife terms. This is a cooperative federal/state activity with the states classifying stream sections as critical, high-priority, substantial, or limited fishery value, using a number of mutually agreed upon criteria. Some states have already completed their portions of the project, while others are just beginning. When all the evaluations have been completed, we will publish a series of maps depicting the relative value of each stream section and a number of reports which document the basis for classification.

A second phase of the stream evaluation project has two major objectives:

1. Quantifying the stream flows required to maintain the characteristics which caused the state to designate the stream sections as highly valued resources.
2. Testing and comparing the efficiency and effectiveness of the various methodologies for making field determinations.

These two objectives are closely related because the broad range of geographic, climatic, and hydrologic conditions which will be encountered in meeting the first objective will provide an excellent laboratory for testing methodologies.

In the light of our current level of funding, we will be required to limit our water quantity determinations at this time to the 10% of the critical stream sections where existing hydrologic information is available for our field-limited methodologies. The methodology testing will be conducted by the Instream Flow Group in cooperation with the states. About half a dozen of the most promising field-intensive methodologies and approaches have been selected for extensive testing and will be used on two to six streams in each state. As the quantification task proceeds, continual feedback in an interactive process among the groups participating will refine the methodologies, improve the skills of the participants, and upgrade the accuracy of the water quantity determinations.

Development of a New Simulation Model

The most exciting outcome of the Instream Flow Program to date is a simulation model recently developed by the Instream Flow Group.

The model uses Riverine Analysis Areas (RAA's), a representative reach concept, target fish species, survival and electivity curves, and simulation modeling techniques. Its objective is to alert decisionmakers to the nature and relative impact of the water requirements for new energy technologies on a range of stream sizes in alternative RAA's or of two or more technologies within the same RAA.

Although the model was designed for regional analysis and evaluation of alternatives, it can be readily adapted to any specific stream, and appears to have the potential for making meaningful incremental analyses of the environmental effects of removing various percentages of water flowing in streams. During the last few weeks, we have been expanding the model to handle the level of detail required for these site specific and incremental analyses and are planning to test its adaptability during Phase II as described above.

When adapted to site specific analysis, the model predicts, through simulation, the change in the standing crop of each fish species in the stream at any average reduction in flow, seasonal variation, or other altered stream flow characteristic. Populations of the various species are shown to go up or down in absolute and relative terms depending on how their particular needs are affected by the changes in flow.

A technical Advisory Panel assisted us in developing the model and also in identifying streams throughout the conterminous United States with nationally important fishery values. A map showing these stream reaches is currently being reproduced. It is intended that these Nationally Significant Stream Reaches serve as an initial set of fish and wildlife priorities for water resource planners until the Instream Flow Information System can be expanded to the remainder of the country.

SIGNIFICANCE OF THE PROGRAM TO ENERGY DECISIONMAKING

The Instream Flow Program expects to benefit energy decisionmaking by encouraging sound planning, research, and implementation of technologies using domestic energy resources. It directly responds to management needs, since it is aimed at alternative site selection and trade-off evaluation which occur during the planning and design phases of energy development. In addition, to this major thrust, we are responding to the needs of decisionmakers at a number of levels for various types of information. For example, our information can be used in establishing broad national policy and allocating resources for research and development among competing energy technologies. At the local level, our improved methodologies can determine in a credible and more acceptable manner the flow which must be maintained in any specific stream to support the natural ecosystem.

More specifically, the methodologies improved as a result of our Instream Flow Program have the following effects:

1. Improved capability of environmental scientists and energy engineers to create, define, and/or develop alternatives that reconcile the two conflicting national objectives of energy development and protection of environmental values.
2. Less disruption to the energy research and development program through more accurate assessment of environmental needs

and early identification of alternatives which minimize conflicts with environmental protection.

3. Reduced possibility of serious setbacks in meeting time schedules due to litigation during construction and plant implementation phases.

The maps to be published as part of the Stream Evaluation Project will depict the relative value of stream fisheries in 15 Western States. These will be distributed to state and local governments, federal development agencies, industrial users, the environmental community, and the public. It is expected that this information will be used by the recipients to direct development away from highly valued fishery resources. The four value classifications further define the appropriate future action regarding streams in each classification. Streams placed in Value Classification I represent the highest-valued resources in the state, and alteration of these streams is considered intolerable by the states. Streams placed in Value Classification IV represent the lowest-valued resources in the state, and if water resource developments are to occur, it is recommended that such development be on these streams. Projects affecting streams placed in Value Classifications II and III would require site-specific studies, and proposed mitigation measures would have to be agreed upon by the developer before the fish and wildlife agencies could look favorably on their development.

The Nationally Significant Stream Reaches identified with the assistance of the Technical Advisory Panel will provide decisionmakers with information in the remainder of the country which will enable them to avoid siting developments on or near these streams. Such early input can reduce study time costs and delays caused by the environmentally unacceptable siting of developments.

The simulation model was developed for the Water Resources Council as part of the Water for Energy Assessment Program and will assess the instream impact of proposed new energy technologies, such as coal gasification and oil shale conversion. With this methodology, the relative impacts of these technologies upon fish in stream reaches located in different areas of the country can be evaluated without the delay of obtaining site-specific data. Such a methodological approach conforms to the requirements of Section 13(a) of the Federal Nonnuclear Research and Development Act of 1973.

If we are successful in adapting this methodology to the local level, we will have broken three major barriers to the assessment of instream flow needs related to time, cost, and incremental analysis. In short, we will have provided a quick and inexpensive tool which will permit a decisionmaker to choose the level of a fishery he wishes to maintain as he balances environmental water needs against other uses.

CONCLUSIONS

The Instream Flow Program is aimed at improved methodologies for determining instream flow needs, providing access to study results completed in the past, and providing planners and decisionmakers with information on fish and wildlife priorities for specific streams and an indication of the volume of stream flow necessary to sustain these resources.

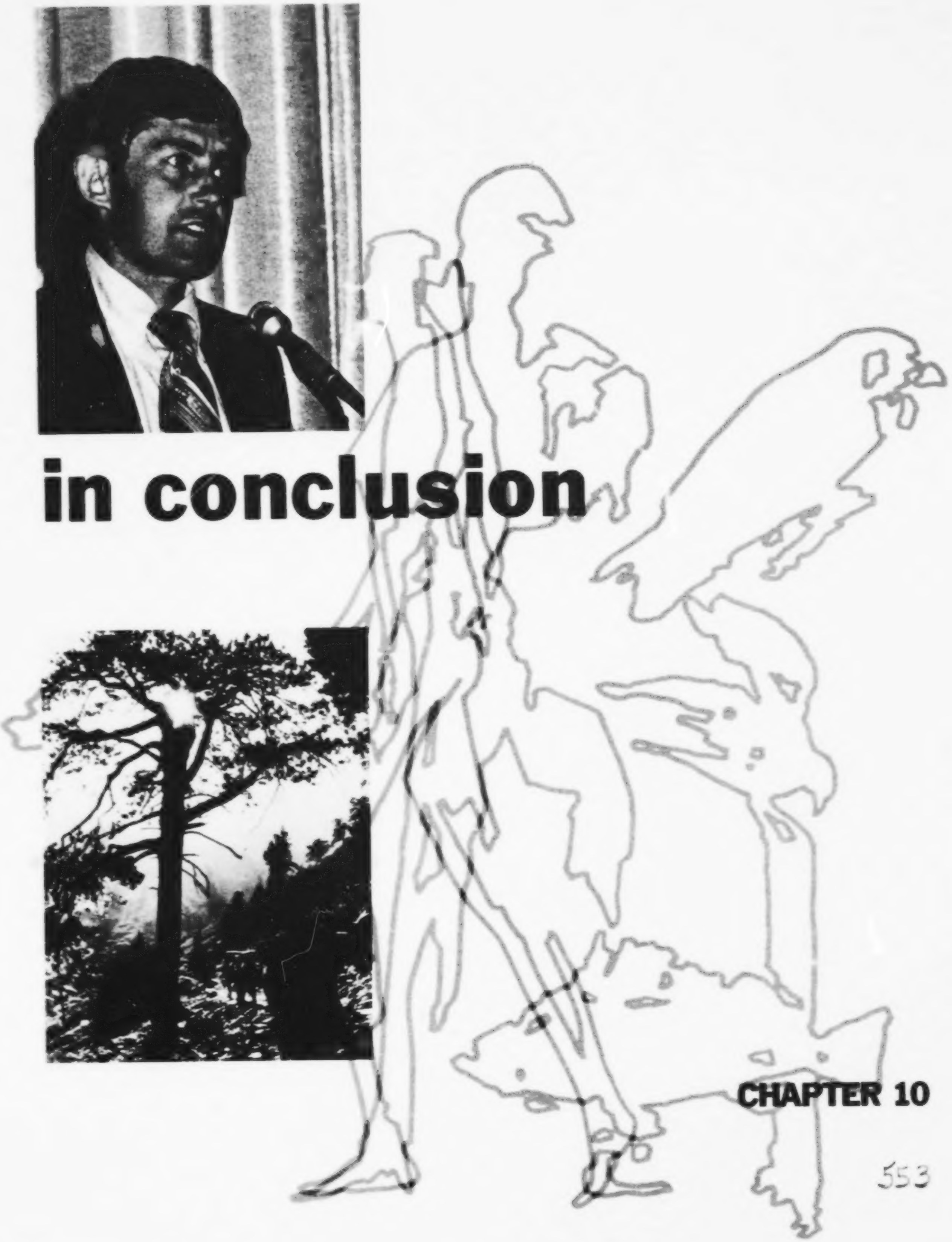
Priority stream sections are being identified in the Western states and we are beginning to assess the stream flow needs of these highly valued stream sections. Through this process, we are developing improved methodologies and increasing the ability of planners to consider the ecological effects of out of stream water uses.

Significant progress has been made in the last 2 years, but this must be considered as only the first step toward adequately addressing the total instream flow problem. If additional funds were made available, the Program could quickly expand into any or all of the following areas:

1. Determining the instream flow needs for all the critical and/or high priority streams in the Western states.
2. Classifying streams in the remainder of the country in terms of environmental values.
3. Determining the instream flows required to maintain the values identified.
4. Addressing other areas of the instream flow problem such as the instream flows needed to maintain estuaries and upland habitat alteration effects.

CHAPTER 10

in conclusion



in conclusion

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Office of Research and Development
U.S. Environment Protection Agency

The comments that I have received to date indicate that this, our Second Interagency Program conference, was a gratifying success. There were some constructive criticisms, and I will touch on those later.

The conference did communicate the sense of where the program is, and where the program is going. It also conveyed a good sense of where we stand in this country on energy and environmental policy. Our thanks to excellent presentations by John O'Leary and Douglas Costle for putting our efforts into the context of overall national policy. The appearance of Dr. Friberg, who spoke on the latest Swedish findings on energy-related carcinogens, added a sense of the international scope of energy/environmental problems.

One very important message came through in the presentations: *our energy futures are less constrained than our environmental futures.* Both Administrators O'Leary and Costle stressed the notion that environmental resources are indeed limited and must be managed, and that energy and environmental conflicts are often false conflicts. Very often other issues are at stake but are obscured by the rhetoric of an environmental/energy clash.

That idea was tied to the concept that our nation take a more conservative approach to exploring our resources. The environment, minerals, and energy are not in infinite supply. Our very social, political, and economic structure must inexorably begin to operate on the assumption that our environmental and mineral resources *are* limited, and that substitutability itself can cause considerable havoc with our social system.

One of the emerging issues broached at the conference concerns the pollutant nitrogen oxide and its derivatives. Nitrogen oxides represent a very important challenge to our experts working on health effects, atmospheric transport and transformation and control technology. This is a subject that we will be emphasizing in our mid-course corrections.

We see in this particular subject a very acute coupling between politics and science and technology. Administrator Costle, in his appearances on the Hill recently, has been questioned very sharply on the nitrogen oxides issue by one astute Congressman who made a very clear political point with respect to nitrogen oxides. He asked the question, how many fewer tons of coal are you going to be able to burn under President Carter's conversion plan because of the delay in nitrogen oxides control on automobiles? That may or may not be a precise statement of the problem, but it does demonstrate how politics comes into play in bringing about alternative environmental strategies. A thought to ponder: where would we be today in attempting to move rapidly towards coal combustion without electro-static precipitators and scrubbers to control particles and sulfur oxides?

Another challenging concept, or at least one which strikes me as exceedingly challenging: What kind of a task do we really have ahead in studying the potential health and environmental threat of the 500, 1,000, or more chemicals which may be present in the products or by-products of fossil fuel processing? It is a fairly staggering thought. The Clean Air Act identified six pollutants as regulated or "criteria" pollutants, and we are still wrestling with those pollutants and their derivatives in the environment. What about the 100 to 1,000 that we now have on the suspect list?

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The conference has appropriately, if somewhat diffusely, captured the state of flux in environmental protection today. A very important shift is occurring — a shift from the old criteria pollutants in the air, for instance, to new pollutants. This shift is seen in the reference to benzo-alpha-pyrene and the potential health impacts of that substance, for example, and the change in the emphasis on what types of effects are being addressed, such as carcinogenic effects as opposed to the increased enhancement of asthma and of other respiratory diseases.

We are also seeing a shift from old technologies, such as conventional power plants, to new technologies, such as oil shale and coal liquefaction. We are beginning to see a very important and yet clearly targeted shift away from the local to the regional impacts of pollutants. The atmospheric transport and transformation session put the sulfur dioxide and sulfates question in its starkest form.

This year's conference has identified much progress on specific engineering projects — scrubbers, coal cleaning plants, mobile pollutant test rigs, pollutant identification, and fluidized bed combustors to name a few. In addition, the program's progress on a number of specific scientific efforts — mutagenic screening, bioaccumulation in ecosystems, and transport and transformation of atmospheric pollution on a subcontinental range — is becoming apparent and what we see is encouraging.

Among the comments I received was one on scientific and technical information. How do we give a program overview — a sense of what is happening, a sense of the wholeness and the interconnectedness of the various activities — and still present technical and scientific information? It is a tough nut to crack.

We had pressure to let more of the technical experts running the program's 600-plus separate projects present more of their own work rather than having it summarized. We will be looking at this question very carefully and may have simultaneous sessions next year. Perhaps we will retain the present format and leave the communication of the scientific and technical results in their full detail to professional meetings and professional journals. We do not have an answer to this, and we would appreicate any additional comments that you might have. Outside the conference format, however, we have taken a major initiative to improve communications. We have inaugurated our Energy/Environment R&D Decision Series of special publications to highlight developing scientific issues and to present the latest technical information. This effort is the key to our goal of informing policy and decision-makers and the interested public on matters which will impact the way all of us live.

In closing, I would like to recall something that happened on the first morning of the conference. As I slipped past Peanuts and Doonesbury in my newspaper (my major source of views on the world), my eye caught the horoscopes. It was a good commentary for the entire conference; "Libra: state your finest ideas to associates and gain their cooperation to put them across. Try to improve your environment."

I could not think of a better thought to leave you with.

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	OEA	Office of Environmental Affairs
DOE	U.S. Department of Energy	
DOI	U.S. Department of Interior	
	BOM	Bureau of Mines
	FWS	Fish and Wildlife Service
	USGS	Geological Survey
EPA	U.S. Environmental Protection Agency	
	EMSL	Environmental Monitoring and Support Laboratory
	ERL	Environmental Research Laboratory
	ESRL	Environmental Science Research Laboratory
	HERL	Health Effects Research Laboratory
	IERL	Industrial Environmental Research Laboratory
	OEMI	Office of Energy, Minerals and Industry
ERDA	Energy Research and Development Administration	
FEA	Federal Energy Administration	
FPC	Federal Power Commission	
HEW	U.S. Department of Health, Education and Welfare	
	NIEHS	National Institute of Environmental Health Sciences
	NIOSH	National Institute of Occupational Safety and Health
HUD	U.S. Department of Housing and Urban Development	
NASA	National Aeronautics and Space Administration	
TVA	Tennessee Valley Authority	
USDA	U.S. Department of Agriculture	
	ARS	Agricultural Research Service
	CSRS	Cooperative State Research Service
	ERS	Economic Research Service
	FS	Forest Service
	SCS	Soil Conservation Service

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